Instream Flow Studies Pennsylvania and Maryland

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Susquehanna River Basin Commission
1721 N. Front Street
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SUSQUEHANNA RIVER BASIN COMMISSION

The Susquehanna River Basin Commission was created as an independent agency by a federal-interstate compact* among the states of Maryland, New York, Commonwealth of Pennsylvania, and the federal government. In creating the Commission, the Congress and state legislatures formally recognized the water resources of the Susquehanna River Basin as a regional asset vested with local, state, and national interests for which all the parties share responsibility. As the single federal-interstate water resources agency with basinwide authority, the Commission's goal is to effect coordinated planning, conservation, management, utilization, development and control of basin water resources among the government and private sectors.

*Statutory *Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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This study was conducted under contract ME94002 between Pennsylvania Department of Environmental Protection and Susquehanna River Basin Commission. Pennsylvania Fish and Boat Commission, the Baltimore District U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency, Chesapeake Bay Program also provided funding for the study.

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EXECUTIVE SUMMARY

Existing procedures for determining instream flow protection levels have certain deficiencies, which result in conflicts between agencies that regulate water supply withdrawals and agencies that manage fisheries. To overcome these deficiencies, the Pennsylvania Department of Environmental Protection, the Susquehanna River Basin Commission, Pennsylvania Fish and Boat Commission, U.S. Army Corps of Engineers, Maryland Department of the Environment, and the Biological Resources Division of the U.S. Geological Survey cooperatively conducted an instream flow needs assessment study. The Chesapeake Bay Program also provided funding for the study. The goal of the study is to develop a procedure for determining instream flow protection levels that: (1) is based on fishery resource protection; (2) is clearly applicable to Pennsylvania streams; (3) does not require expensive site-specific studies; and (4) can be easily applied during the administrative review of applications for surface water allocations.

The basic approach to the development of the procedure is to conduct instream flow needs assessments at sites selected to be representative of a study region, and then regionalize the results of the site-specific assessments to develop the procedure. Only sites with reproducing trout populations and drainage area less than 100 square miles were included in the study.

Physical habitat components of the Instream Flow Incremental Methodology were applied to selected study sites in the Ridge and Valley Freestone, Ridge and Valley Limestone, Unglaciated Plateaus, and Piedmont Upland study regions in Pennsylvania and Maryland. The evaluation species are brook and brown trout. Habitat suitability criteria were selected from the literature, and tested to see if they adequately represented habitat usage on Pennsylvania streams. These criteria were found not to be applicable to Pennsylvania. New criteria were developed from the data collected for the transferability study.

Study streams were selected from available information, and divided into segments based on length of the stream. Study sites were selected near the midpoint of each segment. All study sites had good access, reproducing trout populations, and good water quality. Field data and hydraulic modeling provided estimates of the amount of habitat available within a specified range of flows. The amount of habitat available for all life stages present in a defined season of the year was determined for that range of flows.

A computer program was developed to estimate the effects of withdrawals and passby flows on physical microhabitat and availability of flow for withdrawals. The program estimates a number of statistics of the impact for various combinations of withdrawal and passby flow for any project site in the study regions, including the long-term (average annual) impact. This computer program was run with many combinations of species, withdrawal and passby flow for selected study sites within a given class of study sites (study region, segment class) to estimate the average annual reduction in habitat resulting from each combination. These results were used to prepare graphs of constant habitat impact, and the percent of time that water supply is unavailable, for different levels of impact.

The impact curves can be used to develop statewide policies regarding which impact curve(s) should be used to establish passby flows. They also can be used to determine impact of a proposed withdrawal at any site in these study regions. These curves also can be used by water purveyors to analyze stream intake alternatives that meet state fishery protection levels on cold water streams having drainage areas less than 100 square miles. The determination of which impact curve(s) to use will have to consider costs both to the environment and to withdrawal users. Obviously, the curve with the lowest habitat impact provides the greatest protection to the fishery habitat. However, as the degree of habitat protection increases, so does the percent of time that withdrawals cannot be made because of flow limitations or passby flow requirements.

Although regional criteria have been developed, the computer program also can be used to evaluate conditions not considered in the development of the regional criteria. A regional hydrology procedure has been developed to provide hydrology for the computer program.

A detailed description of the methodology developed and applied in this study, and recommendations for additional studies, are presented.

1.0 NEED FOR STUDY

Historically, instream flows downstream of public water supply sources in Pennsylvania have been protected through mandated conservation releases from major water supply reservoirs or mandated passby flows at smaller dams and intake structures. These conservation flows were first imposed through the surface water allocation program under the auspices of the Pennsylvania Water Rights Act of 1939.

The procedures for determining conservation flows have changed over the years. Prior to the mid-1970s, instream flow protection levels were based on an assumed average low flow of 0.15 cubic feet per second per square mile (csm) of drainage area above the dam or intake structure. In the mid-1970s, the Pennsylvania Department of Environmental Resources (Pa. DER), now Department of Environmental Protection (Pa. DEP), developed a new procedure through the State Water Plan Program. This procedure established instream flow protection levels based upon the 7-day, 10-year low flow ($Q_{7\text{-}10}$), adjusted by a factor related to the magnitude of the withdrawal per square mile. This procedure was later refined to account for seasonal variability in low flows on High Quality and Exceptional Value streams (Pennsylvania Code, Title 25, Chapter 93).

These procedures are considered standard-setting, because they do not address the effect of withdrawals on the habitat or population of the fishery resources, and because the conservation flows are derived from hydrologic records, utilizing a statistical low flow. The $Q_{7\text{-}10}$ flow was originally developed to ensure that violations of water quality standards occurred very infrequently (less than 1 percent of the time).

In 1992, discussions regarding the validity of the procedure based on the $Q_{7\text{-}10}$ flow, resulted in an informal agreement between Pa. DEP and the Pennsylvania Fish and Boat Commission (PFBC) to use, to the extent practicable, a procedure based upon the Tennant Method (Tennant, 1976). That method, which determines conservation flows as a percentage of average daily flow (ADF), also is a standard-setting procedure, but attempts to incorporate aquatic resource needs, based upon field data and observations.

Pa. DEP agreed to use the Tennant-based method, despite the agency's posture that the method does not directly apply to Pennsylvania streams, and the percentages of ADF that are applied may be higher than necessary. Consequently, the conservation flows may unnecessarily reduce the yield that can be obtained from water supply sources, while providing more than adequate protection to the aquatic resources.

Pa. DEP and other interested agencies, including the Susquehanna River Basin Commission (SRBC), recognized the deficiencies of the existing procedures. They wanted to conduct appropriate investigations in Pennsylvania to develop a procedure for determining instream flow protection levels that: (1) is based on fishery resource protection; (2) is clearly applicable to Pennsylvania streams; (3) does not require expensive, site-specific studies; and (4) can be easily applied during the administrative review of each application for a surface water allocation.

SRBC's responsibilities for managing the water resources of the Susquehanna basin include protecting instream flows through the regulation of: (1) certain water withdrawals where signatories to the Susquehanna Compact (Susquehanna River Basin Commission, 1972) do not have the authority; and (2) consumptive use of water.

SRBC adopted a consumptive water use regulation (18 CFR §803.42) that requires new consumptive users to compensate for their consumptive use to protect instream water uses. Although the reservoir releases and other consumptive use actions are currently triggered when flows drop to the Q_{7-10} level, the commission intends to conduct an instream flow study on the main river system to determine whether the trigger level should be modified.

The State of Maryland is interested in the development of new methodology for determining flows that protect biota and also allow water supply withdrawals. The state also is concerned about the implementation of any regulations developed as a result of the study.

The State of Maryland, through its water allocation program, uses the Maryland Most Common Flow Method (letter from R. C. Lucas, Md. Dept. of the Environment, to D. R. Jackson, November 18, 1991) to establish conservation flow requirements for water supply withdrawals and reservoir projects. The method assumes that for any stream and any specified time period flows in the range between 85 percent and 50 percent probability of exceedance on a monthly basis are naturally most common, and that those flows are within the tolerance range of the biota in the stream. The conservation flow is selected in that range, and flows vary with different time periods, depending on the natural flows. Flows near the lower end of the range provide more instream flow protection, while flows near the upper end of the range provide more periods when withdrawals can be made.

There are many important instream flow protection issues. Among the priority issues are:

- The effect of withdrawals and consumptive uses on aquatic biota in cold water trout streams;
- The effects of withdrawals and consumptive uses on aquatic biota in tributary streams with warm water fisheries;
- The effect of withdrawals and consumptive uses on the aquatic biota in major rivers; and
- The effect of consumptive uses on the receiving waters of the Chesapeake Bay.

Existing conflicts between instream and withdrawal uses demonstrate the need for answers to these issues. Prior to this study, there was no usable information available to resolve these issues.

The interested parties determined the first issue to be the most important, because of existing critical conflicts between withdrawals and instream uses on cold water streams. This study will focus on that issue, but the remaining issues should be addressed in additional studies in the near future.

2.0 STUDY CONCEPTS AND PROCEDURES

2.1 Overall Study Plan for Determining Instream Flow Needs

The purpose of this study is to develop a procedure for determining instream flow needs for streams with naturally reproducing trout populations, in portions of Pennsylvania and Maryland, that does not require a stream-specific impact analysis study.

The two study requirements are: (1) the procedure must be habitat-based; and (2) instream flow needs must be easily derived from hydrologic records and data developed in the study.

The basic approach to the problem is to conduct instream flow needs assessment studies at selected representative sites and then regionalize the results of the site-specific assessments to develop the generalized procedure.

Only reproducing trout streams (streams with naturally reproducing trout populations) are included in this study, because the effects of withdrawals on instream uses are most critical on those streams.

A number of methods for determining instream flow needs are found in the literature. The two methods applied in this study are the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982) and the wetted perimeter method (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989). The IFIM method was selected because it is the most sophisticated method presently available for determining instream flow needs, and because it is specifically designed to assess effects of man-made changes in flows such as water supply withdrawals on the habitat available for fish. The wetted perimeter method was selected because it has frequently been used by other investigators to establish instream flow protection levels.

The results of the wetted perimeter method can be compared to the results of the IFIM analysis, especially for effects of changes in flow on riffle transects.

The overall study plan to develop the procedure included the following steps:

- Classification of trout streams based on common characteristics;
- Development and selection of study regions;
- Application of the IFIM methodology to selected study streams within each study region; and
- Application of the wetted perimeter method to determine whether the method furnished information useful for determining instream flow protection levels.

Application of the IFIM methodology included:

- Selection of evaluation species;
- Selection and testing of habitat suitability criteria (HSC) obtained from the literature;
- Development of new HSC;
- Selection of study streams within study regions;
- Selection of representative study sites on the study streams;
- Development of habitat versus flow relationships for the study sites;
- Development and application of impact assessment methodologies utilizing these habitat versus flow relationships to assess impacts on the study streams; and
- Development and application of an impact assessment methodology for the study regions, based on the impact assessment for the study streams.

Each of these steps will be described in detail in subsequent sections.

2.1.1 <u>Methods for evaluating instream flow needs</u>

2.1.1.1 Description of IFIM methodology

The IFIM methodology was originally developed to determine man-made impacts on fishery habitat in a specific reach of a single stream. To the authors' knowledge, IFIM has not been used previously to develop regional or general criteria for determining the impacts of withdrawals for a number of streams classified into similar groups.

Certain components of the IFIM methodology were used in this study to estimate impacts of different combinations of natural flow and withdrawal on physical microhabitat. The methodology used in the study includes the following steps, as shown in the flow chart in Figure 2.1:

- Fish species that are important recreationally, economically, or ecologically are selected and used to evaluate impacts of changes in flow.
- HSC are developed to describe the usability of depth, velocity, substrate, and cover for each life history stage (adult, juvenile, fry, spawning) for each evaluation species.
- Depth, velocity, substrate and cover are used to represent the habitat available for fish species present in the stream.
- Water surface elevation is measured for different flow conditions at each study site.
- Velocity distribution, substrate and cover are measured at one flow.
- The depth and velocity measurements are used to calibrate a hydraulic model.
- The hydraulic model is used to simulate the depth and velocity for a range of flows.
- The simulated depth and velocity values, and the substrate and cover measurements are combined with HSC for each evaluation species and life stage to determine the habitat available over a range of flows. Habitat is defined as weighted usable area (WUA), expressed in units of square feet per thousand feet of stream.
- The amount of habitat available for natural conditions is compared to the habitat available for modified conditions to evaluate the impact of the modifications on habitat.

In the methodology, one or more transects are established for each site. Then numerous measurement points are selected across each transect at points where the depth, velocity, substrate, or cover change. In effect, the transects and measurement points collectively describe the stream as a series of quasi-rectangular areas or cells, each centered on a transect.

The methodology uses the Physical Habitat Simulation (PHABSIM) computer program for hydraulic model calibration and physical habitat simulation. The hydraulic model is calibrated for each cell, and the calibrated model(s) is (are) used to estimate depth and velocity for other flow conditions.

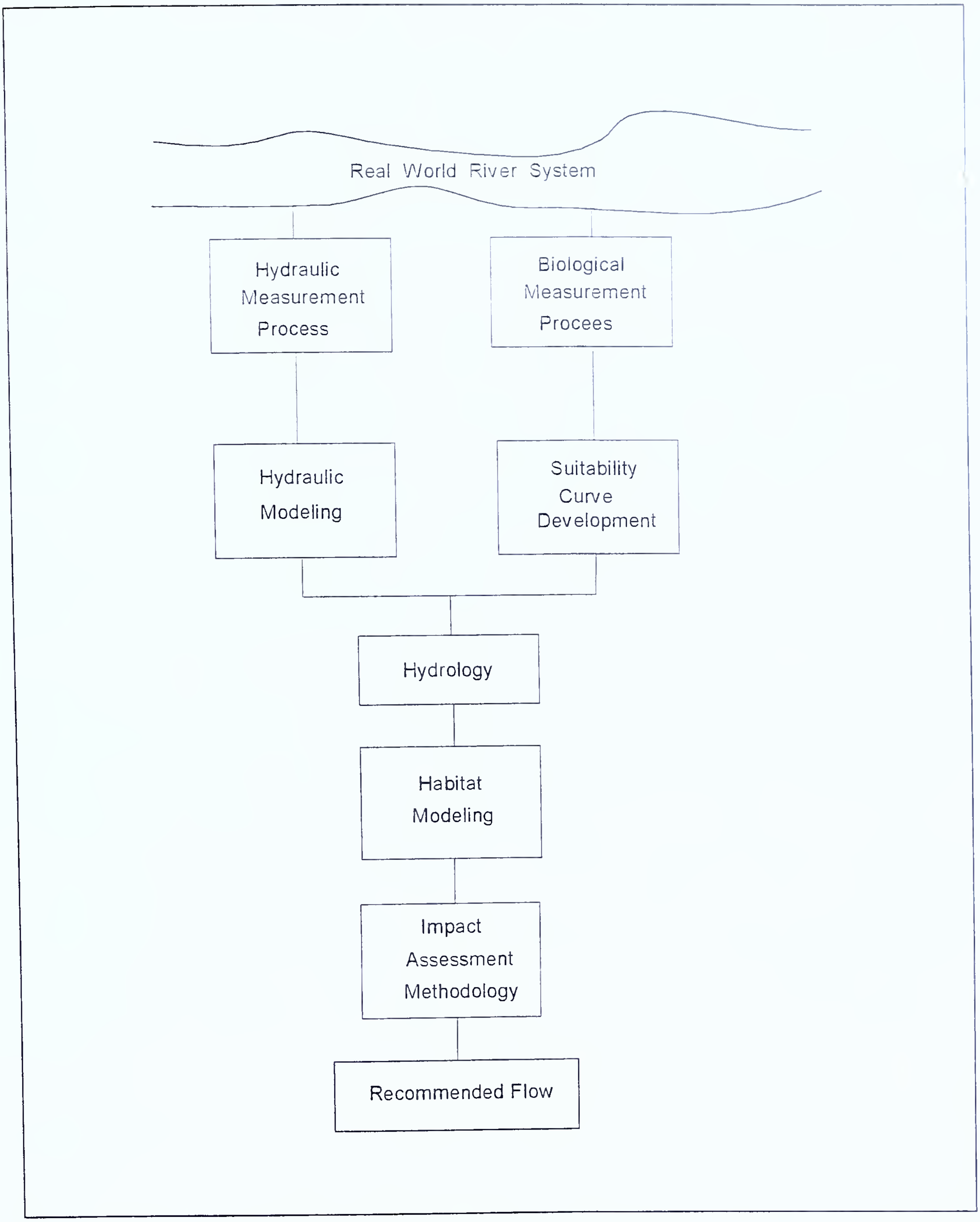

Figure 2.1. Components of Instream Flow Incremental Methodology

2.1.1.2 Description of wetted perimeter method

The wetted perimeter method uses field measurements or hydraulic modeling to determine how the wetted perimeter of a study stream changes with flow. Wetted perimeter generally increases rapidly with flow for flows less than some amount, and then increases less rapidly for higher flows. Wetted perimeter is plotted versus flow, and the flow value at the change in slope of the curve (inflection point) is assumed to be the amount of flow needed to protect the biota.

Typically, the wetted perimeter method is applied to riffle area(s) of the stream channel, because riffles are known to be the most productive areas for aquatic invertebrates, which are the food base for certain species of fish (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989). Sufficient riffle habitat is necessary to produce this food (Leathe and Nelson, 1989).

One of the problems with the wetted perimeter method is the difficulty and subjectivity of determining inflection points. Wetted perimeter curves frequently have two or more inflection points, as described by Leathe and Nelson (1989). Those authors define the upper inflection point as the optimal habitat (and corresponding flow), because almost all the available riffle area is wetted. They also define the lower inflection point as the minimum acceptable flow, because the rate of loss of habitat for lesser flows is unacceptable. They then select a flow in the range between the upper and lower inflection points as the instream flow requirement.

The wetted perimeter method has the advantage of being quick and inexpensive to apply. However, the method has a number of questionable assumptions and limitations (Leonard and others, 1986; Mohrhardt, 1987). The major assumption is that the flow at the inflection point needs to be maintained to ensure an adequate food supply for the fish, but this assumption has not been verified. The method does not allow evaluation of the effects of withdrawals on the biota.

2.1.1.3 Comparison of IFIM and wetted perimeter methods

Leathe and Nelson (1989) list five major factors (Hall and Knight, 1981) that control fish abundance in streams: streamflow; habitat quality; food abundance; predation; and movement and migration. Any of these may be the limiting factor for any given stream. Standard setting methods such as the wetted perimeter method identify minimum flow standards, while incremental methods such as IFIM quantify tradeoffs between withdrawals and instream uses by examining the response of fish habitat to changes in flow (Leathe and Nelson, 1989).

Where man-made changes in streamflow such as withdrawals limit the amount of habitat available, a method that evaluates the effects of incremental changes in streamflow such as IFIM is probably most appropriate. The wetted perimeter method may be appropriate where food supply is the limiting factor, or when a simple method is needed to develop basinwide standards for use in preliminary watershed planning (Leathe and Nelson, 1989).

2.1.2 <u>Evaluation species</u>

Selecting appropriate evaluation species for IFIM studies is important because all interpretations of environmental impacts are based on the effects on the habitat used by the evaluation species (Bovee, 1995).

Originally, brook trout, brown trout, white sucker, blacknose dace, and slimy sculpin were considered as possible evaluation species for the cold water streams included in this study. To focus on the species that are most important economically and recreationally, and reduce the amount of work

required, only brook trout and brown trout were used in the study. The months when each life stage is expected to be present also was determined.

2.1.3 Habitat suitability criteria selection, testing, and development

Habitat suitability criteria can be developed based on field observations for a specific stream, or group of streams, or can be obtained from the literature. Prior to this study, HSC had not been developed for streams in Pennsylvania or Maryland. The criteria in the literature have been developed by various investigators for streams in other parts of the country. The National Biological Service (now Biological Resources Division, U.S. Geological Survey) recommends that HSC obtained from the literature be tested to determine whether they are applicable to other areas.

Procedures for developing HSC are described by Bovee (1986) and Bovee and Zubov (1988), but they are very resource-intensive and expensive, and beyond the resources available for this study. For that reason, HSC were selected from the literature for depth and velocity for all four life stages of each evaluation species. Criteria for substrate and cover were developed based on professional judgement. These steps are described in section 3.1. Then the transferability of the criteria to Pennsylvania was evaluated, by collecting and analyzing habitat usage data for four streams in two study regions in Pennsylvania, as described in sections 3.2 through 3.6. The evaluation showed the criteria obtained from the literature are not satisfactory for use in habitat modeling for Pennsylvania streams. New criteria were developed from the data collected during the transferability study, as described in section 3.7.

2.1.4 Classification of trout streams

2.1.4.1 Stream classification purpose

To develop a regional procedure for assessing impacts of withdrawals on any stream in a region, the streams need to be classified according to important characteristics related to fishery habitat. Once the streams have been classified, typical streams can be selected from each class. The results of instream flow assessments for these typical streams can be used to estimate the effects of withdrawals on other streams within the region. Since trout streams are found in all parts of Pennsylvania, the classification scheme needs to apply to the entire state.

The purpose of the stream classification system was to identify classes of streams that have similar key physical features. Key physical features are those that have a direct influence on the physical variables (depth and velocity) and stream attributes (substrate and cover) used to quantify fish habitat. Similar, in this case, means that all the sampled streams within a class are expected to have a comparable WUA versus discharge relationship, if the flow variable is normalized to minimize the effects of watershed size. Similarity of the streams implies the WUA versus discharge relationships, aggregated across the sampled streams within a class, should be representative of any stream within the class.

2.1.4.2 Stream classification scheme

Streams with cold water fisheries were classified according to study regions, which were selected to represent different geology and topography. Within each study region, streams were further classified according to slope. Because slope was difficult to determine for such a large number of streams within the time constraints for this study, length was used as a surrogate for slope, as described in section 4.3. Streams were divided into an appropriate number of segments, based on an appropriate length of segment. The length of segment was based on statistical analysis of stream length

data, as described in section 4.3. Segments were numbered from 1 to 4, and streams with the same segment number in a study region were assumed to be similar.

Most of the trout streams in Pennsylvania have drainage areas less than 100 square miles. Larger streams are generally too warm during the summer months to allow trout reproduction. Smaller streams present the greatest concern, because of the large number of water supply withdrawals located on them, and the potential impacts of the withdrawals on trout species. All the study segments had drainage areas less than 100 square miles; therefore, the study results are applicable only to such streams.

2.1.4.3 Development and selection of study regions

Topographic and geologic classification of streams could be based on physiographic provinces and sections, as described by Fenneman (1938), or on ecoregions (Omernik, 1987a, b). The physiographic provinces and sections have been mapped by Pa. DER (now Pa. DEP) (1989), and revised by Sevon (1995). The ecoregion boundaries for Pennsylvania were being remapped at the time the study began (R. Shertzer, Pa. DEP, oral communication), and the boundaries proposed by Omernik (1987b) were not considered satisfactory for this study. Because the ecoregion boundaries developed by Omernik (1987b) are related to the physiographic region boundaries, and the physiographic regions are based on similar geologic and topographic conditions, streams were classified using physiographic provinces and sections, rather than ecoregions.

The physiographic provinces and sections in Pennsylvania are shown in Table 2.1, beginning in the southeastern corner of the commonwealth, and proceeding north and west. These physiographic provinces and sections are shown on the map in Plate 1.

Table 2.1. Physiographic Provinces, Sections, and Study Regions

Province	Section	Study Region
Coastal Plain		
Piedmont	Piedmont Upland Piedmont Lowland Gettysburg-Newark Lowland	Piedmont Upland (freestone)
New England Province	Reading Prong	
Blue Ridge Province	South Mountain	
Ridge and Valley	Great Valley Appalachian Mountain	Ridge and Valley Freestone/Limestone Ridge and Valley Freestone/Limestone
Appalachian Plateaus	Glaciated Low Plateau Glaciated Pocono Plateau Glaciated High Plateau Deep Valleys Allegheny Plateau Allegheny Mountain High Plateau Pittsburgh Low Plateau Glaciated Pittsburgh Plateau	 Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau
Lakes	Eastern Lake	

The stream classification based on physiographic sections was modified, as described below.

The Ridge and Valley Province includes the Great Valley and the Appalachian Mountain sections. Both sections include important trout streams that are underlain by limestone and dolomite rocks (limestone streams), and trout streams that are underlain by freestone (e.g., sandstone, shale, conglomerate) rocks (freestone streams). Limestone streams are known to have different hydrology, are expected to have different habitat characteristics, and to respond differently to water supply withdrawals, than the freestone streams. Therefore, the trout streams in the Ridge and Valley Province were classified into study regions based on limestone/freestone geology, rather than physiographic sections.

The Appalachian Plateaus Province includes nine sections that have different geologic and topographic characteristics. Of these nine sections, four have been glaciated, based on the location of the glacial boundary (Sevon, 1995), as shown in Plate 1. The glaciated streams are known to have different hydrology than the unglaciated streams, and are expected to have different habitat characteristics and response to water withdrawals. For that reason, the difference between glaciated and unglaciated sections is expected to be an important factor affecting habitat. The glaciated and unglaciated physiographic sections were combined into Glaciated and Unglaciated Plateau study regions.

In Pennsylvania, the conflicts between withdrawal and instream uses are most critical on cold water streams in the Ridge and Valley Province, and in the unglaciated parts of the Appalachian Plateaus Province. Accordingly, those parts of the commonwealth were included in the study. Parts of five counties in the Unglaciated Plateau study region were subsequently deleted, because the low yield of surface streams results in few water supply withdrawals from small streams. The areas eliminated included all of Beaver, Allegheny, Washington, and Greene Counties, and a portion of Fayette County in the Pittsburgh Low Plateau physiographic section.

The Piedmont Physiographic Province includes three sections, as shown in Table 2.1. Limestone streams are present in all three Piedmont study regions, and in some cases, limestone has been metamorphosed into marble, which may behave differently. Since there are more reproducing trout streams in the Piedmont Upland freestone region, the Piedmont study streams were selected from that study region.

In summary, this study includes three study regions in Pennsylvania: Ridge and Valley Limestone; Ridge and Valley Freestone; and Unglaciated Plateau; and one study region, the Piedmont Upland (freestone), in Maryland. The relationship between study regions used in this study and physiographic sections is shown in Table 2.1.

2.1.5 Selection of study streams

Lists of reproducing trout streams were developed for each study region from PFBC files, and from an inventory of Maryland cold water fisheries (Steinfelt, 1991). Study streams and segments were selected from these lists in three stages. First, potential study streams were selected by stratified random sampling from the lists of reproducing trout streams in each study region, as described in section 4.4. Second, the study streams and segments were selected in the field from the list of potential study streams, again using a stratified random sampling process, as described in section 4.4. The list of study streams selected in the field is shown in Tables 5.1 through 5.4, and summarized in Table 5.5. Third, certain streams or segments were deleted from this list because of modeling problems, as described in section 5.6.2.

A basic assumption was that 30 stream segments in each study region provided an appropriate level of accuracy for development of the regional procedure. Thirty segments were selected in each study region for data collection and modeling, except for the Piedmont Upland study region.

For the Piedmont Upland study region, sufficient potential study streams were identified to select 30 stream segments in the field. However, funding limitations only allowed 12 stream segments (all in Maryland) to be studied. Additional Piedmont streams should be studied in the future to develop instream flow guidelines for all three Piedmont study regions.

2.1.6 Selection of study sites

Study sites were selected in the field at an accessible location as close as possible to the midpoint of a segment. Crews observed several occurrences of each mesohabitat type (riffle, run, pool), if present, and selected one representative of each type. Then transects were established at the midpoint of each representative mesohabitat type. The procedure is described in detail in section 5.2.

2.1.7 Development of habitat versus flow relationships

Habitat versus flow relationships were developed for each transect, utilizing field data, hydrology, and modeling. During field data collection, water surface elevation was measured at each transect at several different flows, as described in section 5.3. Velocity distribution, substrate, and cover were determined at one flow. Substrate and cover were determined using a classification scheme developed for this study, which is described in section 3.1.2.

Stream gage data were used to develop hydrology for the study sites, as described in section 5.5. Procedures were developed for determining when to dispatch field crews, as described in section 5.5.4.

Hydraulic models were calibrated using the field data for each measurement point, as described in section 5.6. The calibrated hydraulic models and the hydrology were used to determine the velocity and depth values for each cell, each study site, and a large range of flows, as described in section 5.7. These data were combined with the HSC for each life stage of each species to compute WUA versus flow relationships for each transect, species and life stage (section 5.7). The relationships for each transect were combined to produce a composite WUA versus flow relationship for each species and life stage for each study site, as described in section 5.7.

2.1.8 Impact assessment

The IFIM procedure (Figure 2.1) includes assessment of impacts. Procedures were developed to combine the WUA versus flow relationships, produced by the habitat modeling, into composite normalized minimum WUA versus flow relationships for each species and each study site (section 6.3). The resulting relationships were used in three different impact assessment procedures.

The first impact assessment procedure, described in sections 6.4 and 6.5, considered two definitions of habitat loss, no-loss of habitat, and no-net-loss of habitat at the median monthly flow, for establishing stream protection levels. Both criteria were found to significantly restrict withdrawals. For that reason, more detailed impact assessment procedures were developed.

The second impact assessment procedure, described in section 6.6, is designed to analyze time series of median monthly flows for each study site. Other flow statistics or time steps also can be analyzed. A computer program has been written to estimate the impact of withdrawals and passby flows

on the monthly, seasonal, and annual habitat and flow available, and provides summary statistics and duration analyses of the impacts (section 6.6.2 and Appendix E). The program also estimates the impact of natural flows and passby flows on the percent of time the withdrawal can be made. Different combinations of withdrawal and passby flows can be analyzed to compare different scenarios for wild or stocked trout populations. A regional hydrology procedure (section 6.6.3) has been developed for use with the impact assessment program.

The computer program was used to develop a series of constant-habitat-impact graphs, for several levels of withdrawal and passby flow, both expressed as percentage of average daily flow, for the Ridge and Valley Freestone, Ridge and Valley Limestone, and Unglaciated Plateau study regions, as described in sections 6.6.2.4 and 6.6.2.5. The graphs show both the impact of withdrawals and passby flows on habitat, and the effect on the availability of water for withdrawal. These graphs can be used to develop regional or statewide policies regarding acceptable levels of impact on both uses, considering tradeoffs between habitat impact and impact on water users. The curves also can be used to evaluate engineering alternatives for meeting required fishery protection levels on cold water streams having drainage areas less than 100 square miles in Pennsylvania.

The third impact assessment procedure, which is described in section 6.6.4, utilizes flow and associated habitat duration analysis to evaluate impacts of withdrawals, and estimate the appropriate passby flow. The results of this method can be used in establishing regional or statewide passby flow requirements. The impact analysis for individual study streams in Pennsylvania has been completed, but the interpretation of the results has not been completed, due to time and cost constraints.

2.1.9 Wetted perimeter method

Output from the hydraulic model runs was used to plot graphs of wetted perimeter versus flow, as described in section 5.9. This procedure effectively assumes the inflection point occurs in the range of flows between maximum and minimum monthly flows. The inflection points of these graphs were tabulated, and are shown in the same section. Extrapolation of these plots to a point of zero wetted perimeter at zero flow showed that the limited range of simulation flows was not adequate to allow selection of inflection points. Additional field data would need to be collected at extreme low flows for application of the wetted perimeter method.

2.2 Study Organization

The following agencies participated in the study:

- Pennsylvania Department of Environmental Protection (Pa. DEP);
- Pennsylvania Fish and Boat Commission (PFBC):
- Susquehanna River Basin Commission (SRBC);
- Baltimore District, U.S. Army Corps of Engineers (COE);
- U.S. Geological Survey, Biological Resources Division (GSBRD);
- U.S. Fish and Wildlife Service (USFWS);
- Maryland Department of Natural Resources (MDNR).

Pa. DEP, SRBC, PFBC, COE, MDNR, and Environmental Protection Agency Chesapeake Bay Program (CBP) provided funding for the study.

Prior to beginning this study, SRBC established a Water Resources Management Advisory Committee (WRMAC), which identified instream flow needs studies as a priority. WRMAC then established an Instream Flow Subcommittee (IFSC) to provide technical information regarding instream

flow needs, and to develop a study plan. These activities, conducted under SRBC auspices, were integrated with Pa. DEP activities to satisfy their needs.

A Study Steering Committee provided general oversight to the study. The committee included representatives of both public and private interests. Also, a study team that included staff from Pa. DEP, SRBC, PFBC, COE, GSBRD, and MDNR developed the detailed study procedures and provided guidance for the study. SRBC, PFBC, COE, and MDNR staff conducted the field work. SRBC and PFBC staff performed HSC transferability testing and developed new HSC from field data. Hydrology and habitat modeling were provided by SRBC staff. PFBC staff developed the time series impact assessment methodology and computer program, and SRBC staff conducted the impact assessment using that methodology. SRBC staff developed and implemented the flow and associated habitat duration impact analysis methodology. GSBRD provided technical assistance.

3.0 SUITABILITY CRITERIA SELECTION, TESTING, AND DEVELOPMENT

3.1 Habitat Suitability Criteria and Species Periodicity

Initially, brook trout, brown trout, white sucker, blacknose dace, and slimy sculpin were considered as possible evaluation species for this study. White sucker, blacknose dace, and slimy sculpin were considered because they can serve as forage species for trout and frequently occur with trout in coldwater streams. HSC are available for all life stages of white sucker (Twomey and others, 1984). However, white sucker adults are not generally abundant in many of the small headwater trout streams used in this study. Only a limited number of HSC have been developed for blacknose dace and slimy sculpin, and HSC do not exist for all life stages (Sheppard and Johnson, 1984; Mecum, 1984; Trial and others, 1983). Brook and brown trout are the most recreationally and economically important species in the study streams. For that reason, only brook and brown trout were used as evaluation species.

Existing brook and brown trout HSC from the following sources were considered for use in this study: Bovee (1978, oral communication, 1994); Aceituno and others (1985); Raleigh and others (1986); Jirka and Homa (1990); Harris and others (1992); Normandeau Associates Inc. (1992); and Gary Whelan, Michigan Department of Natural Resources (oral communication, 1994).

3.1.1 Depth and velocity criteria

The same depth and velocity HSC were used for brook and brown trout, for transferability testing because the literature indicated very little difference in the criteria for these species. Velocity criteria based on mean water column velocity were used throughout this study. Nose velocity HSC were not used in this study, and were not considered for transferability testing.

The criteria selected for testing are summarized in Table 3.1 and included in Figures 3.1-3.8 (pages 44-51). For adults and juveniles, Normandeau Associates' (1992) depth and velocity HSC were tested. For spawning, Whelan's (oral communication, 1994) depth and velocity HSC were tested. The spawning life stage includes redd (nest) construction, egg incubation, and immature trout to the time of emergence from the substrate.

For brook and brown trout fry, Normandeau Associates' (1992) depth and mean column velocity HSC were originally proposed for transferability testing. However, based on general observations made in the field, SRBC staff believed the Normandeau HSC for fry would not be transferable to the study streams. The Normandeau HSC indicated a suitability index of 1 (optimum) at water depths of 1.31 to 1.61 feet. During field investigations, most fry were observed in shallower water, although deeper water was available. Also, the Normandeau HSC indicated that areas with no current velocity had a suitability index of 0 (unusable). In the field, many fry were found in areas with little or no velocity. The fry criteria in the literature cited above were reexamined, resulting in the conclusion that the Bovee (1978) HSC were more realistic and consistent with the field observations. Bovee's (1978) brown trout fry depth and velocity HSC were used for transferability testing for both brook and brown trout fry.

Table 3.1. Depth and Velocity Habitat Suitability Criteria Used for Transferability Testing

Depth Habitat Suitability Criteria								Velocity Habitat Suitability Criteria							
Normandeau (1992)		Normandeau (1992)		Whelan (1994)		Bovee (1978)		Normandeau (1992)		Normandeau (1992)		Whelan (1994)		Bovee (1978)	
Adult		Juvenile		Spawning		Fry		Adult		Juvenile		Spawning		Fry	
Depth	Index	Depth	Index	Depth	Index	Depth	Index	Velocity	Index	Velocity	Index	Velocity	Index	Velocity	Index
ft		ft		ft		ft		ft/sec		ft/sec		ft/sec		ft/sec	
0	0	0	0	0	0	0.12	0.10	0	0.21	0	0.58	0	0	1.10	1.00
1.00	0	0.50	0.12	0.10	0.08	0.40	0.40	0.10	0.70	0.10	0.88	0.10	0.34	1.20	0.94
1.60	0.40	1.00	0.61	0.20	0.22	0.60	0.93	0.50	1.00	0.50	1.00	0.20	0.72	1.65	0.52
2.00	0.80	2.00	0.84	0.30	0.50	0.85	1.00	1.00	0.69	1.00	0.92	0.30	0.84	2.00	0.30
2.60	1.00	3.00	1.00	0.40	0.96	1.70	1.00	1.50	0.50	1.50	0.70	0.60	1.00	2.20	0.20
4.00	1.00	4.00	0.27	0.50	1.00	1.90	0.97	2.40	0.20	2.00	0.26	1.70	1.00	2.50	0.10
7.00	0.21	7.00	0.24	1.10	1.00	2.20	0.80	3.10	0.03	3.50	0.05	3.00	0	2.65	0.05
100.00	0.21	8.00	0.08	3.00	1.00	2.50	0.54	5.00	0.03	4.30	0			3.00	0
		100.00	0.08	4.00	0	2.70	0.44	6.00	0	100.00	0				
						2.90	0.38	100.00	0						
						3.10	0.36								
						3.25	0.33								
						3.75	0.14								
						4.20	0.08								
						4.70	0.05								
						5.00	0								

3.1.2 Substrate/cover criteria

The substrate and cover classification schemes shown in Table 3.2 were used in this study. Combined substrate/cover HSC, that were tested are shown in Table 3.3. Both the classification scheme and the HSC were based on professional judgment of the investigators. Substrate and cover combinations were identified based on a two-digit coding system. The first digit referred to the substrate type, and the second digit referred to the cover type. Fifteen substrate/cover combinations were therefore possible. For example, substrate/cover type 1.1 consists of silt or sand with no cover, type 1.2 consists of silt or sand with object cover, and so forth.

Table 3.2. Classification Scheme for Substrate and Cover

Substrate Type

1 - Diameter of <3 mm. (silt, sand)
2 - Diameter of 3 mm.–64 mm.
3 - Diameter of >64 mm.

Cover Type

1 - No cover
2 - Object at least 6 inches high and with a cross section horizontal measurement of at least 1 foot
3 - Undercut object along bank
4 - Aquatic vegetation
5 - Terrestrial vegetation <1 foot above water surface

Table 3.3. Substrate/Cover Habitat Suitability Criteria Used for Transferability Testing

Substrate/ Cover Codes	Spawning HSC	Fry HSC	Juvenile HSC	Adult HSC
1.1	0	0.5	0.5	0.5
1.2	0	1	0.8	0.8
1.3	0	1	1	1
1.4	0	1	0.8	0.8
1.5	0	1	0.8	0.8
2.1	1	0.5	0.5	0.5
2.2	1	1	0.8	0.8
2.3	1	1	1	1
2.4	1	1	0.8	0.8
2.5	1	1	0.8	0.8
3.1	0	1	0.8	0.5
3.2	0	1	0.8	0.8
3.3	0	1	1	1
3.4	0	1	0.8	0.8
3.5	0	1	0.8	0.8

3.1.3 Periodicity chart

One important component of the Instream Flow Study is the recognition of specific time periods when the various life stages of each species will be present in the study streams, which is called periodicity. The periodicity chart, shown in Table 3.4, was developed after reviewing pertinent literature and discussing brook and brown trout life history information with PFBC and Penn State University fisheries biologists.

Table 3.4. Periodicity Chart for Brook and Brown Trout

Life Stage	Month											
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Adult	x	x	x	x	x	x	x	x	x	x	x	x
Juvenile	x	x	x	x	x	x	x	x	x	x	x	x
Spawning	x	x								x	x	x
Fry			x	x	x	x						

3.2 Selection of Study Streams for Transferability Testing

Lanka and others (1987) state that trout stream habitat in the Rocky Mountains is greatly influenced by drainage basin geomorphology. Similarly, Nelson and others (1992) found trout distribution in the North Fork Humboldt River drainage area of northeastern Nevada to be related to geologic district and land type association.

The physical and biological characteristics of reproducing trout streams vary greatly among physiographic regions in Pennsylvania, as well as between limestone and freestone streams. No one stream could be selected for HSC modeling that contained all habitat types found in reproducing brook and brown trout streams in the commonwealth. Transferability testing could not be performed for all study streams described in section 4.0 because of resource limitations. To evaluate whether the HSC could be transferred to the study streams, it was assumed that if the HSC could be transferred to one stream in each study region, they also could be transferred to other streams in the same study region. In the Ridge and Valley Limestone region, only one stream (Big Spring Creek, Cumberland County) was identified that has only a reproducing brook trout population. For that reason, that region and species combination was not considered for transferability testing. Therefore, transferability studies were proposed for one stream from each of the following categories:

- Ridge and Valley Limestone study region, reproducing brown trout stream;
- Ridge and Valley Freestone study region, reproducing brown trout stream;
- Ridge and Valley Freestone study region, reproducing brook trout stream;
- Unglaciated Plateau study region, reproducing brown trout stream; and
- Unglaciated Plateau study region, reproducing brook trout stream.

Streams with reproducing trout populations were identified from PFBC data (PFBC, 1993). The criteria used for selecting potential streams for transferability testing were a drainage area of less than 100 square miles, large numbers of reproducing trout, excellent water quality and visibility, and good structural and hydraulic diversity. To facilitate trout identification during sampling, an attempt was made to select streams that did not contain significant numbers of more than one trout species

Field reconnaissance, including electrofishing, was performed in the streams shown in Table 3.5. Results are shown in the table.

Based on the reconnaissance, Elk Creek, Cherry Run, Little Fishing Creek, Young Womans Creek, and Whitehead Run were initially selected as study streams. Both Young Womans Creek and Elk Creek are relatively large streams, compared to the other streams selected. Elk Creek was deleted from the study because of limited water clarity and time and cost constraints. Also, a transferability study on a second large stream would have required more resources than were available

The study streams finally selected represented the Ridge and Valley Freestone and Unglaciated Plateau study regions.

All four study sites are located on forested land, and classified by the PFBC as Class A Wild Trout Waters. PFBC had not stocked the streams with hatchery trout in recent years.

3.3 Description of Study Streams

3.3.1 Cherry Run

Cherry Run originates from a spring in Bald Eagle State Forest, Hartley Township, Union County, Pa. The stream flows in a southwesterly direction into Centre County, continuing onward in that direction until bending towards the southeast to pass through a gap in Paddy Mountain. From the gap, the stream continues in a southeasterly direction, flowing back into Union County and discharging into Penns Creek, about 3.2 miles southwest of Weikert in Hartley Township.

The portion of Cherry Run selected as a study site is about 4 miles long, extending from the mouth upstream through Centre County to the Centre-Union County line. The drainage area at the downstream limit of the study site is 5.9 square miles.

3.3.2 Little Fishing Creek

Little Fishing Creek originates on Nittany Mountain in Bald Eagle State Forest, Spring Township, Centre County, Pa. The stream flows in a northeasterly direction through Hecla Gap, and enters the Nittany Valley at Mingoville in Walker Township. The stream continues onward in a northeasterly direction into Clinton County, where it discharges into Fishing Creek near Lamar, Porter Township.

The portion of Little Fishing Creek selected as a study site is about 4.6 miles long, and extends from Hecla Gap upstream above the Greens Valley Road bridge. The drainage area at the downstream limit of the study site is 5.9 square miles. Although parts of the Little Fishing Creek Watershed are underlain by limestone rocks, this part is underlain by freestone rocks.

3.3.3 Young Womans Creek

Young Womans Creek originates in Sproul State Forest at the confluence of Baldwin Branch and County Line Branch in Chapman Township, Clinton County, Pa. The stream flows in a southerly direction, entering the West Branch Susquehanna River at North Bend in Chapman Township. The U.S. Geological Survey's stream gaging station No. 01545600 is located on Young Womans Creek, about 3.7 miles upstream from the mouth and 1.5 miles upstream from Left Branch Young Womans Creek, which is the largest tributary.

Table 3.5. Streams Considered for Transferability Study

Stream Name	County	Study Region	Expected Trout Species	Date Sampled	Results of Reconnaissance Sampling
Little Fishing Creek	Centre	Ridge and Valley Freestone	Brook	May 16, 1994	Large numbers of brook trout adults, juveniles and fry. Excellent habitat diversity and water clarity.
Elk Creek	Centre	Ridge and Valley Limestone	Brown	May 16, 1994	Large numbers of brown trout, some brook trout. Good habitat diversity, limited water clarity.
Cherry Run	Centre and Union	Ridge and Valley Freestone	Brown	May 16, 1994	Many adult and juvenile brown trout. Excellent habitat diversity and water clarity.
Young Womans Creek	Clinton	Unglaciated Plateau	Brown	May 19, 1994	Large numbers of adult and juvenile brown trout. Excellent habitat diversity and water clarity.
John Summerson Branch	Clinton	Unglaciated Plateau	Brook	May 19, 1994	Insufficient numbers at sampling site near mouth. More abundant upstream according to PFBC, but access to that area was poor.
Trout Run	Clinton	Unglaciated Plateau	Brook	May 19, 1994	Insufficient numbers of fish.
Lost Creek	Juniata	Ridge and Valley Freestone	Brown	June 9, 1994	Large numbers of adult brown trout, relatively few juveniles and fry. Significant numbers of adult brook trout. Excellent habitat diversity and water clarity.
Wallace Run	Centre	Ridge and Valley Freestone	Brown	June 20, 1994	Small numbers of fish. Mixed population of about half brook and half brown trout.
Swift Run	Mifflin	Ridge and Valley Freestone	Brown	June 20, 1994	Mixed population about half brook and half brown trout.
Grove Run	Cameron	Unglaciated Plateau	Brook	June 21, 1994	Large numbers of brook trout, many brown trout.
Montour Run	Clinton and Cameron	Unglaciated Plateau	Brook	June 21, 1994	Insufficient numbers of fish.
Whitehead Run	Cameron	Unglaciated Plateau	Brook	June 21, 1994	Large numbers of brook trout, easily accessible. Good habitat diversity and water clarity. A few brown trout.
Laurel Run	Union	Ridge and Valley Freestone	Brown	June 22, 1994	Mixed population of brook and brown trout. Streambank shading made observations difficult.
Lackawanna River	Lackawanna	Ridge and Valley Freestone	Brown	June 23, 1994	Mixed population of brook, brown, and rainbow trout. Good habitat diversity. Trash and household debris caused health and safety concerns.

The portion of Young Womans Creek selected as a study site extends from the vicinity of the U.S. Geological Survey stream gaging station upstream about 5.2 miles to the vicinity of Beechwood Trail. The drainage area upstream from the gaging station is 46.2 square miles.

3.3.4 Whitehead Run

Whitehead Run originates in Elk State Forest about 4.3 miles northeast of Cameron in Lumber Township, Cameron County, Pa. The stream flows in a westerly direction to meet Hunts Run in Lumber Township.

The entire length of Whitehead Run, including its major tributary, Rock Run, was selected as the study site. The drainage area at the downstream end of the study site is 4.4 square miles.

3.4 Field Data Collection

3.4.1 Procedures

Transferability studies were conducted using the general methodology described by Thomas and Bovee (1993). Field work was performed in general accordance with the field manual, which is included as Appendix A of this report. Microhabitat measurements were taken at locations where undisturbed fish were observed, and in randomly-selected locations where fish were absent.

Bovee (1986) identified size-class as a good method for classifying groups of fish for HSC development. For the purpose of this investigation, fish less than 2 inches in total length were considered to be fry; fish between 2 and 6 inches long were considered juveniles; and fish 6 or more inches long were considered adults. This size stratification scheme is consistent with that cited in most of the HSC literature listed in section 3.1. Spawning locations were identified by the presence of a totally- or partially-completed redd (nest).

All sampling was performed during daylight hours. Sampling was not performed during extremely low flows when habitat diversity was limited, or during extremely high flows when observations would have been difficult or dangerous. At least one flow measurement was taken near the downstream end of the sampling area on all trips, except the spawning sampling trip to Cherry Run, when the flow was estimated.

Equal areas of all mesohabitat types were sampled, regardless of which mesohabitat types were most abundant, or had the greatest concentrations of fish. The locations of all undisturbed fish (or redds) at each mesohabitat sampling site were marked, and appropriate data were recorded.

If two (nonspawning) fish were located within 1 foot of each other, they were considered to be in the same location (PHABSIM cell), and only one set of microhabitat measurements was taken. If a group of fish had individuals less than a foot apart, but the group was spread out over 2 or more feet (which occurred on some occasions with fry), several measurements were made within the occupied area at locations spaced a foot apart. Sampling for adults, juveniles, and fry was generally performed by a three-person crew. However, a four-person crew was used on a few of the juvenile and adult sampling trips, allowing two crew members to simultaneously make microhabitat measurements, and thereby speed up the data collection process. A two-person crew was used for all field trips involving spawning adult fish.

Snorkel gear, surface observations, and electrofishing were used to observe fish locations, which were documented. When identifying fish locations, a conscious effort was made to avoid fish fright and investigator bias.

The effectiveness of using snorkel gear to make direct underwater observations of undisturbed fish has been well documented (Bovee, 1986; Bovee and Zuboy, 1988). For this reason, snorkel gear was used to the maximum extent possible in making in-situ observations of adults, juveniles, and fry for the transferability studies. Snorkel gear was used extensively, and was the preferred means of identifying adult, juvenile, and fry locations in Young Womans Creek. However, the method could not be effectively used in Whitehead Run and Cherry Run, because nearly all of the sampling area were too shallow to sample with snorkel gear. For the same reason, snorkel gear could not be effectively used to sample adult and juvenile locations in Little Fishing Creek, but was used to a limited extent to sample fry locations in pool habitat during higher water conditions. For habitat types that could not be effectively sampled with snorkel gear, surface observations and electrofishing were used to identify fish locations.

When making observations with snorkel gear, the diver used his hands and legs to pull or push quietly along the bottom, moving systematically in an upstream direction to identify the locations of undisturbed fish. In deep water and in areas with extremely fast current, the diver pulled himself through the study reach on a rope, which had been previously anchored.

Surface observations were used in clear, shallow water to locate fish or redds at each mesohabitat sampling site. Because of low flow conditions and excellent water clarity, surface observations were the only means used to identify spawning locations. The observer wore drab or camouflage clothing, and made a cautious approach in an upstream direction through the sampling area, taking care not to frighten fish. Surface observations were generally made with the aid of polarized sunglasses. In some instances, binoculars also were used to assist in making surface observations.

Electrofishing was generally performed with a backpack DC shocker and two hand-held electrodes. However, an AC shocker was used on one of the adult/juvenile sampling trips to Cherry Run, due to equipment malfunction. A rat-tail probe was used as one of the electrodes when sampling fry on all streams, except Young Womans Creek, because of equipment problems. For each point sampled, the electrodes were carefully positioned, the electrical current was then activated, and the locations of fish identified. If necessary, fish were collected with a dipnet for identification or measurement. All collected fish were returned to the stream.

Fish and redd locations were marked with a lead fishing sinker, to which a numbered piece of plastic surveyor's tape was attached. The date, time, mesohabitat type, observation technique, marker tag number, species, length, and life stage were recorded. A copy of the field data sheets used for occupied locations is shown as Appendix 3 of the field manual for HSC transferability testing.

After fish and redd locations were marked, water depth was measured and recorded to the nearest 0.01 foot, using a top-setting rod equipped with a current meter. The number of cup rotations per unit of time was recorded on the data sheet so that mean current velocity for each location could be calculated. Where the water depth was less than 2.5 feet, one current meter reading was taken at six-tenths of the distance from the water surface to the stream bottom. Where the water depth was greater than 2.5 feet, one current meter reading was taken at two-tenths and another reading was taken at eight-tenths of the distance from the water surface to the stream bottom. The results of the two velocities were averaged. Water temperature in degrees Celsius was periodically measured and recorded.

Before removing the fish location markers from the stream bottom, a random sampling procedure was used to select locations that were unoccupied by fish. The procedure is described in Appendix A.

Unoccupied locations were not selected within 1 foot of an occupied location. Data were collected and recorded on a copy of the field data sheet for unoccupied locations, shown as Appendix 4 of the field manual.

The dates of field observations and a record of streamflow measurements are shown in Table 3.6. Relatively large variations in streamflow occurred in Young Womans Creek due to rain and thunderstorm activity. On some occasions, sampling had to be delayed until water clarity improved and stream conditions stabilized. Under these circumstances, care was taken to avoid delays in taking microhabitat measurements after occupied and unoccupied locations were identified, because of changing flow conditions.

3.4.2 General observations

Young Womans Creek was ideally suited for use of snorkel gear. Excellent water clarity normally allowed a diver to spot adult fish that were more than 20 feet away, if they were approached cautiously by moving in an upstream direction. The tendency of fish to remain in position when approached by a diver varied with the life stage, water conditions, current velocity, and cover being used by the fish and diver at the time of observation. In general, adult fish were more difficult to approach than juveniles, and juveniles were more difficult to approach than fry. As a general rule, adult fish in open, moving water could be approached to within about 10 feet before showing fright reactions (ceasing to feed on drifting material, making jerky or tense body movements, preparing to dart away, gradually moving away from the diver, etc.). When cover was available, adult trout could be approached even more closely. Some large brown trout resting under rock ledges could almost be touched by the diver. Many juveniles continued to feed when only a few feet from the diver, and some fry could be approached to within inches of the face mask.

Initially, only brown trout data were collected when sampling for adults and juveniles in Young Womans Creek. However, both brook trout and brown trout were observed in the stream. During the second field visit, microhabitat data were collected for both species.

In Young Womans Creek, positive species identification of undisturbed adults and juveniles was an easy matter because of excellent underwater visibility, the magnification effect caused by looking through the diver's mask, and the fact that fish were moving naturally with fins spread and markings easily visible. Species identification of fry was dependent on being able to see a dark spot on the adipose fin of brook trout. This spot is not present on brown trout. Eighty-nine fry locations were sampled in Young Womans Creek. However, because of the small size of the fry (0.75 to 1.25 inches) and the fact that many of the smaller fish were heavily pigmented, field identification to the species level was not always possible. Thirty-three of the fry from these locations were identified as brook trout, 14 were identified as brown trout, and 42 could not be accurately identified.

In Young Womans Creek, brook trout seemed to be more commonly associated with pool habitat, while brown trout appeared to be more closely associated with cover. Brown trout were more abundant in the lower region of the study area (in the vicinity of the U.S. Geological Survey gaging station). Brook trout were more abundant in upstream areas (from Bull Run upstream to the vicinity of Beechwood Trail).

Table 3.6. Sampling Dates and Streamflow Measurements

Type of Fish/ Dates Sampled and Streamflow	Cherry Run	Little Fishing Creek	Young Womans Creek	Whitehead Run
Adult/Juvenile Sampling, First Data Set				
Dates Sampled	July 25-27, 1994	July 11-13, 1994	July 6,7,8,13, & 14, 1994 July 20-21, 1994 August 8-9, 1994	July 18-20, 1994
Streamflow	1.68 cfs (July 25, 1994)	1.54 cfs (July 11, 1994)	110 cfs (July 6, 1994) 80 cfs (July 7, 1994) 47 cfs (July 13, 1994) 45 cfs (August 8, 1994)	4.84 cfs (July 20, 1994)
Adult/Juvenile Sampling, Second Data Set				
Dates Sampled	August 22-25, 1994	September 6-8, 1994	August 10-11, 1994 August 15-17, 1994	August 29-31, 1994 September 1, 1994
Streamflow	5.90 cfs (August 23, 1994)	2.80 cfs (September 8, 1994)	36 cfs (August 10, 1994) 31 cfs (August 11, 1994) 219 cfs (August 15, 1994) 186 cfs (August 16, 1994) 153 cfs (August 17, 1994)	9.58 cfs (September 1, 1994)
Spawning Sampling				
Dates Sampled	November 3-4, 1994 November 7-8, 1994	October 18-21, 1994	October 24-26, 1994	October 10-14, 1994
Streamflow	4 cfs (estimated)	2.21 cfs (October 21, 1994)	12 cfs (October 24, 1994)	0.78 cfs (October 14, 1994)
Fry Sampling				
Dates Sampled	April 17-19, 1995	April 24-26, 1995	May 8-11, 1995	May 1-3, 1995
Streamflow	6.73 cfs (April 19, 1995)	8.15 cfs (April 24, 1995)	27 cfs (May 8, 1995) 26 cfs (May 10, 1995) 156 cfs (May 11, 1995)	2.20 cfs (May 3, 1995)

During all of the field trips to Little Fishing Creek, the only species of trout observed was brook trout. Some brown trout were observed during the fall in the lower portion of Whitehead Run, but the predominant species present was brook trout. The predominant species present in Cherry Run was brown trout, although some brook and rainbow trout also were observed.

When identifying redd locations, it was important to look very carefully for gravel that had been disturbed. In many cases, the pit (depression) and tailspill (downstream area of loose gravel) of redds were difficult to identify, especially if the redd was small and not recently constructed. Because small brook trout make small redds, it was necessary to look carefully in even small pockets of gravel. The tailspills for some redds were only slightly larger than the 6- or 7-inch long fish that made them. Larger fish made larger redds, and some brown trout redds in Young Womans Creek were found with tailspills that were more than a foot long. Redds were frequently found in the tails of pools, but they were found in all mesohabitat types (riffles, runs, and pools).

As recommended by Dr. Robert Carline of Penn State University, field crews used a walking stick to poke into potential redd locations to determine if the sediments were loose and may have been excavated by trout. It was often possible to dislodge eggs to confirm the site was, in fact, a redd by digging with the stick to a depth of several inches (depending on the size of the redd). Crews initially dug into the bottom sediments by hand to confirm redd locations, and used a fine-meshed screen colander to catch dislodged eggs. However, digging with a walking stick was just as effective, and was much less damaging to redds.

Redds were much easier to identify with good lighting (such as during the middle of a sunny day) and when there was little or no wind to create a surface disturbance on the water. Most redds were found in relatively flat, shallow water. However, some were found in areas with almost no flow, and a few were found in relatively choppy water. Side channels seemed to be especially productive locations, probably because flow was reduced and gravel was more abundant in many of these areas. Redds were more easily identified when they were occupied by fish.

Although brown trout were actively constructing redds when Cherry Run was sampled for spawning, no eggs were recovered from redd locations. For this reason, it was assumed that sampling had been conducted at the beginning of the spawning period.

Eggs were recovered from redds on all three of the other streams sampled. Based on the appearance of redds and the activity of fish, sampling was conducted somewhat after the peak spawning activity on Little Fishing Creek and Whitehead Run. Many brown trout were found occupying redds in Young Womans Creek, indicating sampling probably occurred during the time of peak spawning activity. Although a few brook trout also were seen on redds in Young Womans Creek, the majority of redds observed in that stream were made by brown trout.

3.5 Transferability Study Data Analysis Procedures

Field data were used to perform transferability testing of HSC in accordance with the procedures cited by Thomas and Bovee (1993). The number of occupied and unoccupied sites (cells) having optimum usable, suitable, and unsuitable habitat were calculated for the appropriate study streams, species, and life stages. For this test, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more (Bovee, oral communication, 1994). One-sided chi-square tests (alpha = .05) were performed using the formula shown below.

$$T = \frac{\sqrt{N}(ad - bc)}{\sqrt{(a+b)(c+d(a+c)(b+d)}}$$

where: T = the test statistic
a = the number of occupied optimum (or suitable) cells;
b = the number of occupied usable (or unsuitable) cells;
c = the number of unoccupied optimum (or suitable) cells;
d = the number of unoccupied usable (or unsuitable) cells; and
N = the total number of cells.

To be considered transferable, the test statistic had to be greater than 1.6449.

For the purpose of data analysis, all redds observed in Young Womans Creek were assumed to be brown trout redds, unless brook trout were observed at a particular redd location. Insufficient brook trout redds were observed to warrant use of data from these redds for transferability testing.

Brook, brown, and unidentified fry data from Young Womans Creek were considered collectively for the purpose of transferability testing.

3.6. Transferability Study Data Analysis Results

Transferability testing indicated the HSC discussed in section 3.1 were not transferable to most of the streams tested. The results of transferability testing are summarized in Table 3.7. Chi-square test results used in compiling Table 3.7 are shown in Appendix B.

Table 3.7. Results of Transferability Testing

Stream and Species	Life Stage	Transferable?
Cherry Run, Brown Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No
Little Fishing Creek, Brook Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No
Young Womans Creek, Brown Trout	Adult	Yes
	Juvenile	No
	Spawning	No
	Fry (Brook and Brown)	No
Young Womans Creek, Brook Trout	Adult	Yes
	Juvenile	No
Whitehead Run, Brook Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No

3.7 Criteria Development

3.7.1 Procedures

Because only a few of the HSC were transferable, the following options were considered

1. Collect additional data and develop new HSC for testing;
2. Test other existing HSC;
3. Modify the HSC and rerun the transferability test; and
4. Develop new criteria from data already collected.

Option 1 would have been the most desirable, if additional time and funds had been available. Development of individual sets of new criteria for each of the transferability study streams would have required about four times as much work as the transferability testing that had already been performed. Therefore, new criteria were developed based on the data available from the transferability studies. All the data collected for each species and/or life stage were pooled to develop the new HSC.

Prior to developing the new criteria, histograms were prepared of the occupied and unoccupied site data used for transferability testing. Additional HSC were identified and compared visually to the histograms to see whether there was a match. Since there was no match, the modified forage index and the linear index, described by Schreck and Moyle (1990), were both used in a systematic approach to developing new HSC.

The forage ratio is an electivity index used to measure the degree to which fish select for specific food items available to them in the environment. It also may be used to describe the degree of preference for various microhabitat conditions (Bovee, 1986). This concept was applied to the selection for depth, current velocity, substrate, and cover in the environment per the histogram analyses. Modified forage index ratios were calculated for each depth, velocity, and substrate/cover bin[1] used in the histogram analyses. The formula used to calculate the modified forage index is:

$$FR = r_i/(p_i+1)$$

where: FR = the modified forage index;
r_i = the percentage of occupied sites in depth, velocity, or substrate/cover bin i; and
p_i = the percentage of unoccupied sites in depth, velocity, or substrate/cover bin i.

The formula cited by Schreck and Moyle (1990) used only "p_i" as the denominator. However, we decided to add 1 percent to the denominator so that an index could be calculated when the number of unoccupied sites was zero. After calculating the modified forage indexes, they were normalized (put on a scale of 0 to 1) to permit comparison with the HSC.

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[1] The first depth bin for adults, juveniles, and spawning (0.13 feet) was for water depths of 0-0.25 feet, the second bin (0.38 feet) for water depths of 0.25-0.50 feet, etc.

The first velocity bin for adults, juveniles, and spawning (0.13 feet/second) was for velocities of 0-0.25 feet/second, the second bin (0.38 feet/second) for 0.25 to 0.50 feet/second, etc.

Depth and velocity bins used for fry were made half as large as the above (intervals of 0.06 feet or feet/second, instead of 0.13 feet or feet/second, respectively) because of the narrow range of depths and velocities for sites occupied by fry.

The linear food index was first proposed by Strauss (1979) and is

$$L = r_i - p_i$$

where: L = the linear index, and r_i and p_i are as defined above.

The modified forage index always has positive values. However, values for the linear index range from -1 to +1, with positive values indicating preference and negative values indicating avoidance. No attempt was made to normalize the linear indexes.

3.7.2 Depth and velocity criteria

Normalized modified forage indexes (NMFIs) for depth and velocity for each life stage and stream were plotted on the same graphs as the depth and velocity HSC used for transferability testing, and are shown as Figures 3.1 through 3.8.

Brook trout NMFIs for Little Fishing Creek, Whitehead Run, and Young Womans Creek were used to develop new adult and juvenile brook trout HSC. Brown trout NMFIs for Young Womans Creek and Cherry Run were used to develop new adult and juvenile brown trout HSC.

New HSC for spawning brook trout were developed using NMFIs for Little Fishing Creek and Whitehead Run. New HSC for spawning brown trout were developed from NMFIs for Young Womans Creek and Cherry Run.

Because of the close similarity of fry NMFIs for all four streams, new HSC for fry were developed from data collected from all four streams, and brook and brown trout fry HSC were considered identical.

When developing new depth and velocity HSC using data from several streams, the data point with the higher NMFI from each bin was generally used. The new HSC may, therefore, be considered conservative because they encompass data from all of the streams considered. If a question arose regarding a particular data point (such as a modified forage index calculated from relatively few fish observances), the linear index also was considered in developing the new HSC.

The NMFI for fry depth in Whitehead Run (Figure 3.4) is a value of 1 at depths of 0.94 feet and 1.19 feet. This produced an unusual peak in the graph for Whitehead Run that was much different from peaks in the graphs for the other streams. Because of the small number (2 out of 57) of fry observations made at the above depths in Whitehead Run, these data points were not used to construct the revised criteria, and the depth with the next highest NMFI (0.56 ft.) was considered to have a suitability index of 1.

3.7.3 Substrate and cover

Prior to constructing new substrate/cover HSC, modified forage indexes were calculated for all 15 combined substrate/cover categories. Modified forage indexes also were calculated independently for all three substrate types and for all five cover types. The independently calculated substrate and cover modified forage indexes were most easily analyzed and were used to develop new HSC. The NMFIs used to develop new substrate/cover HSC are shown in Table 3.8.

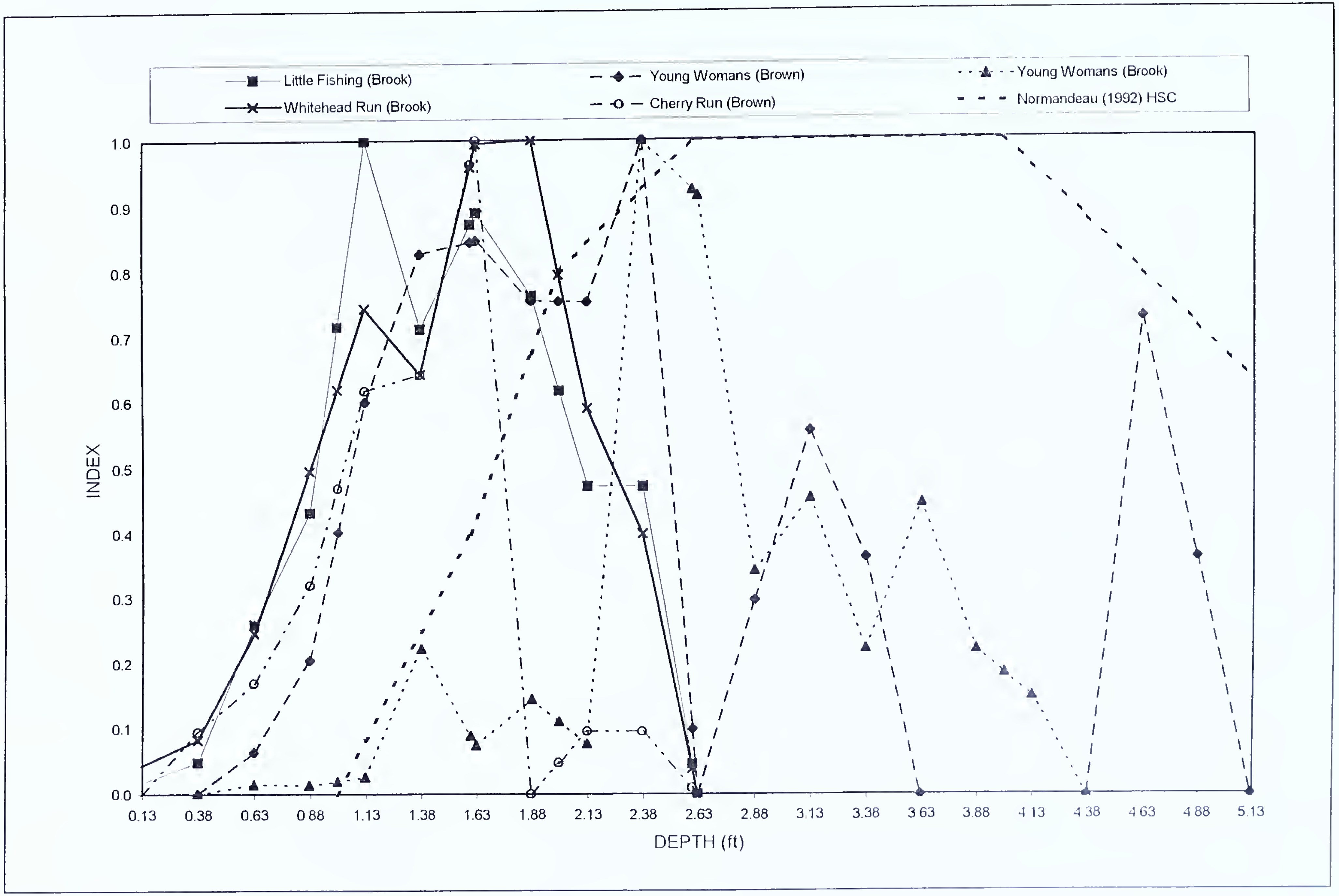

Figure 3.1. Adult Normalized Modified Forage Indexes for Depth

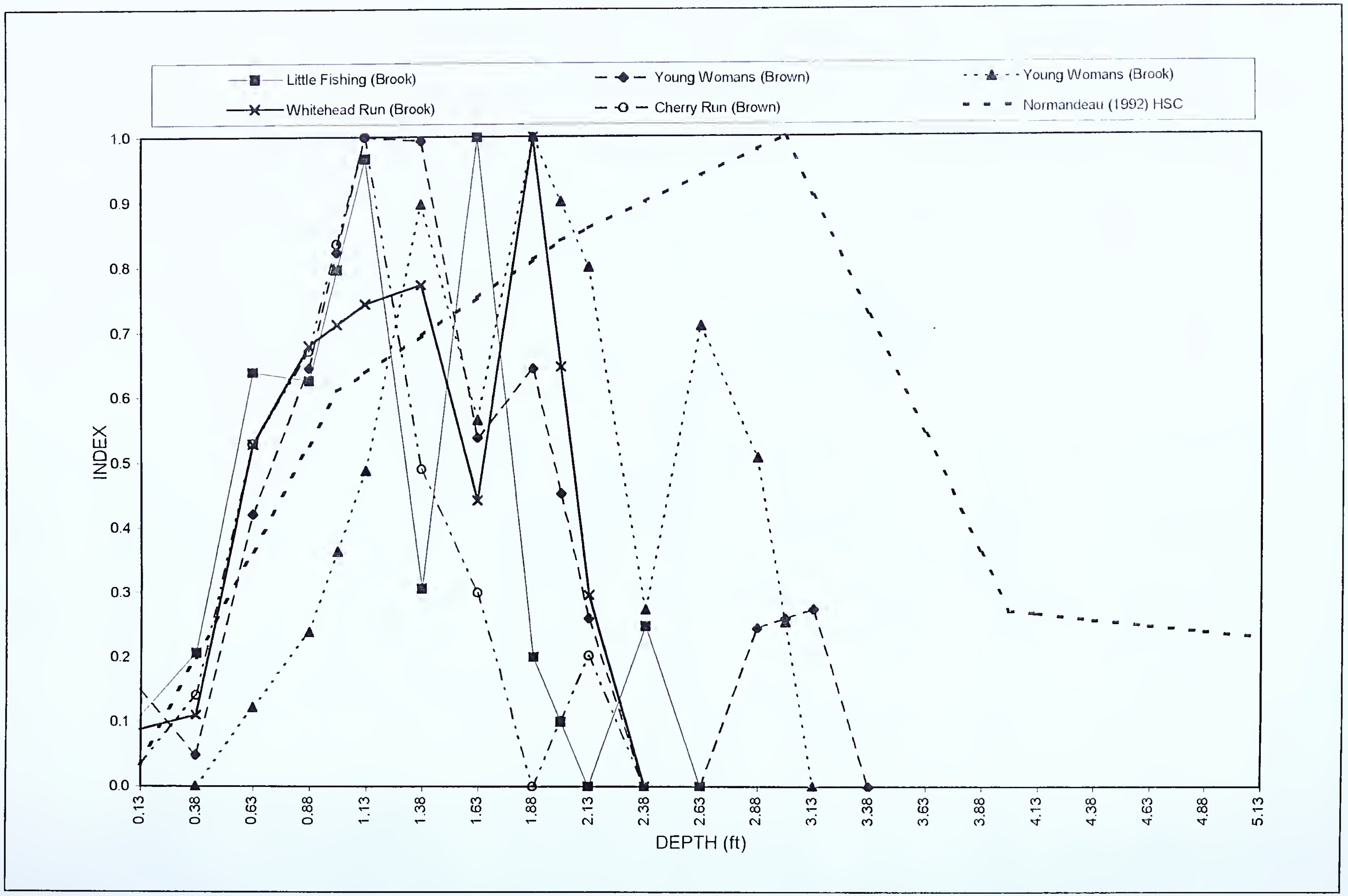

Figure 3.2. Juvenile Normalized Modified Forage Indexes for Depth

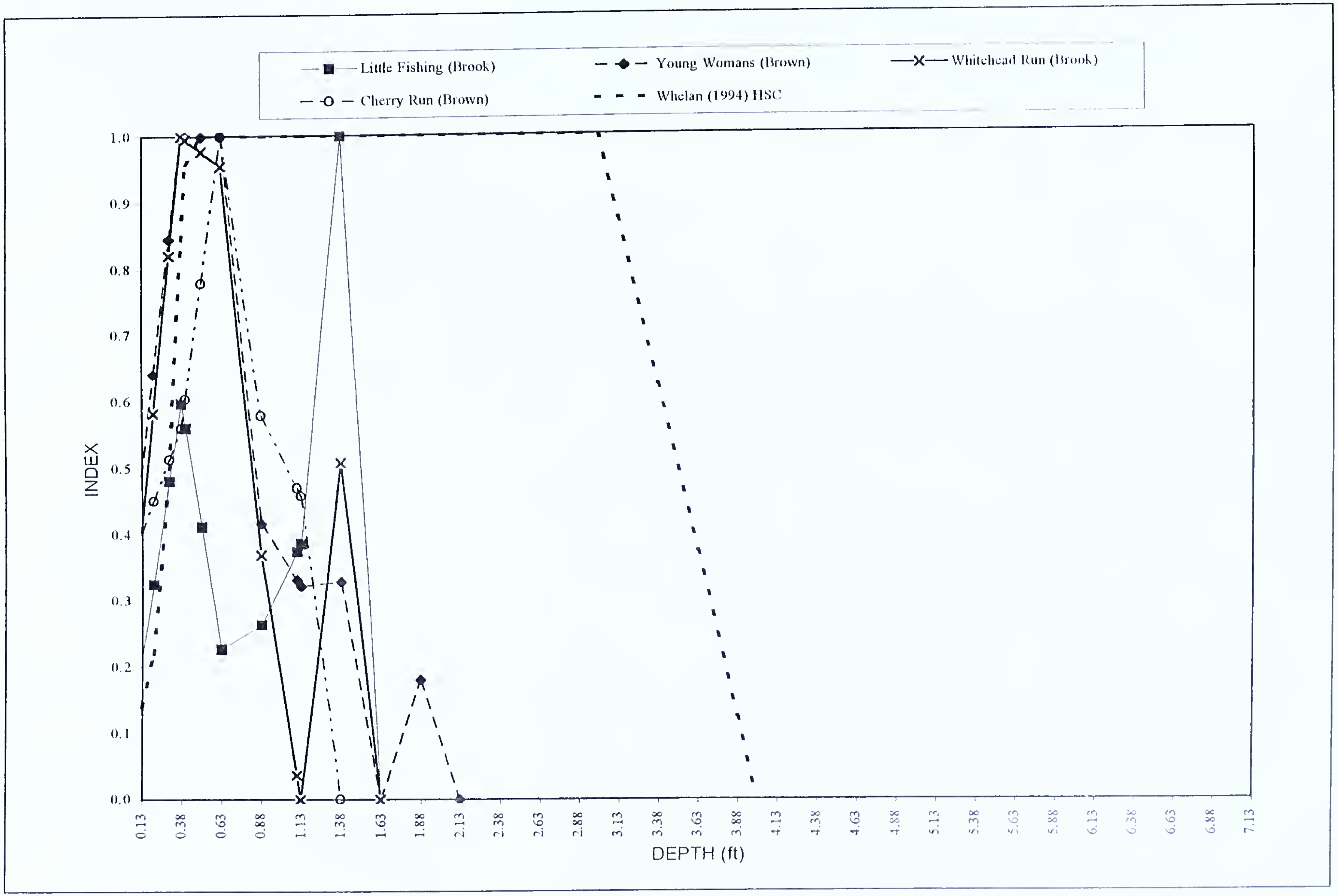

Figure 3.3. Spawning Normalized Modified Forage Indexes for Depth

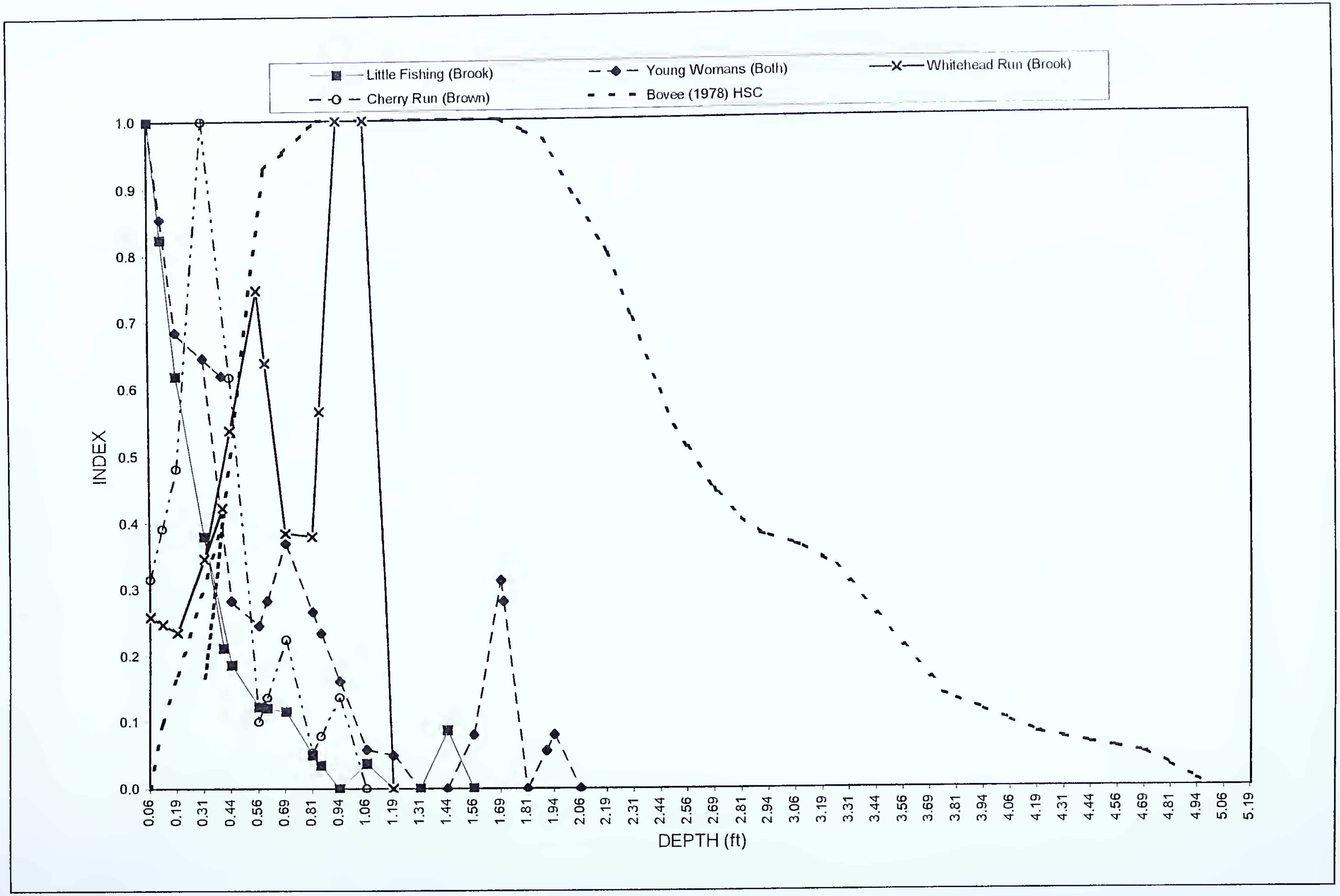

Figure 3.4. Fry Normalized Modified Forage Indexes for Depth

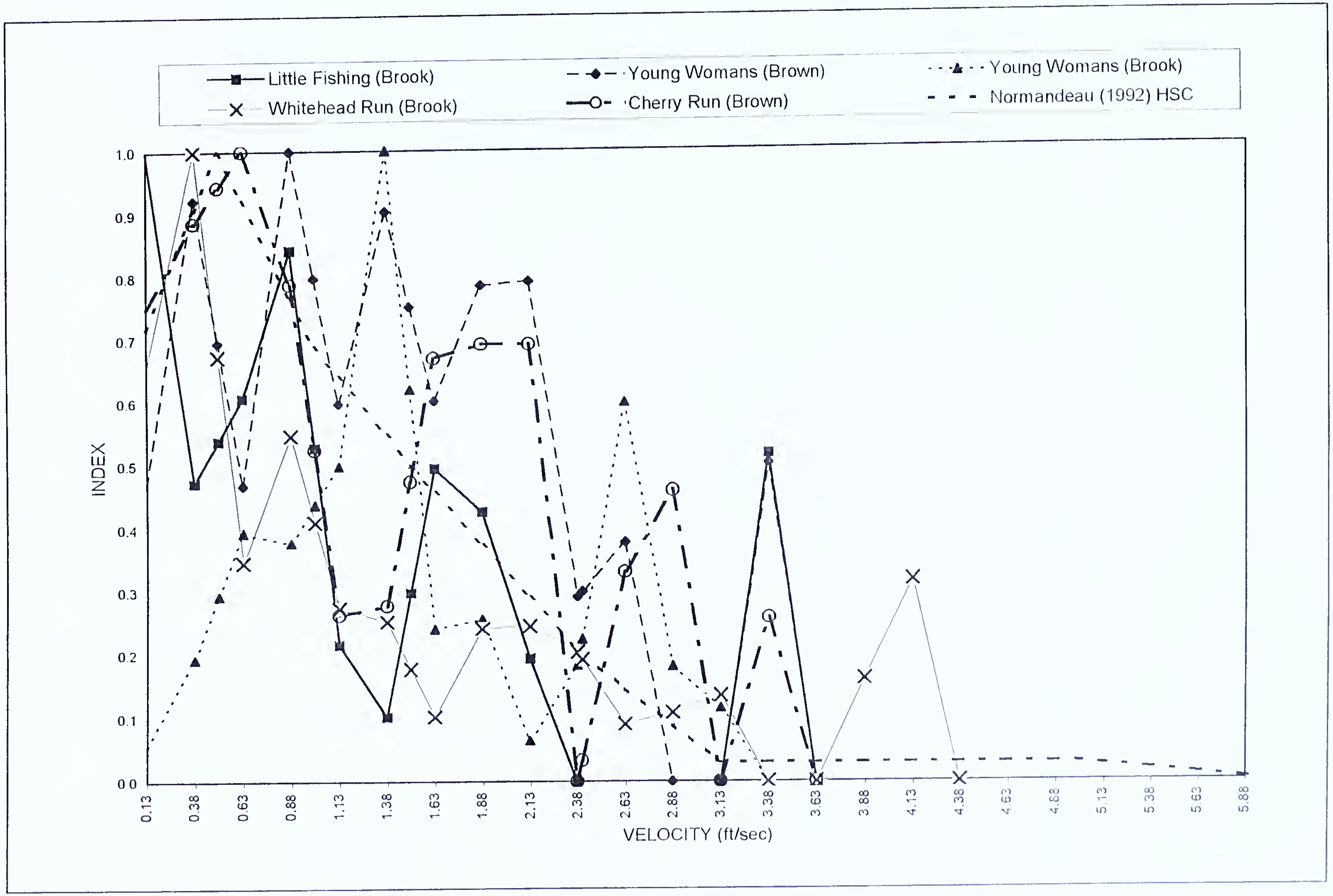

Figure 3.5. Adult Normalized Modified Forage Indexes for Velocity

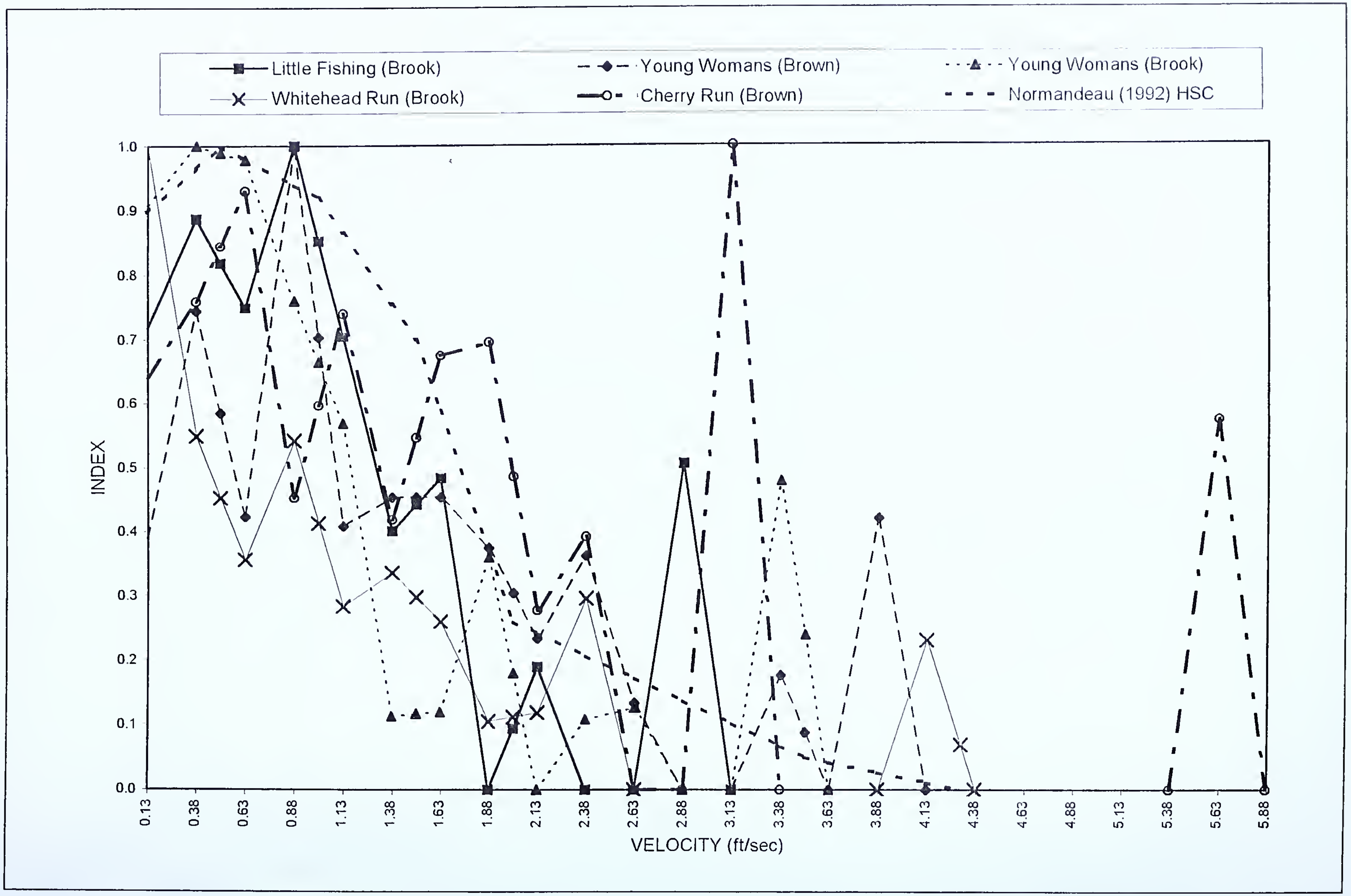

Figure 3.6. Juvenile Normalized Modified Forage Indexes for Velocity

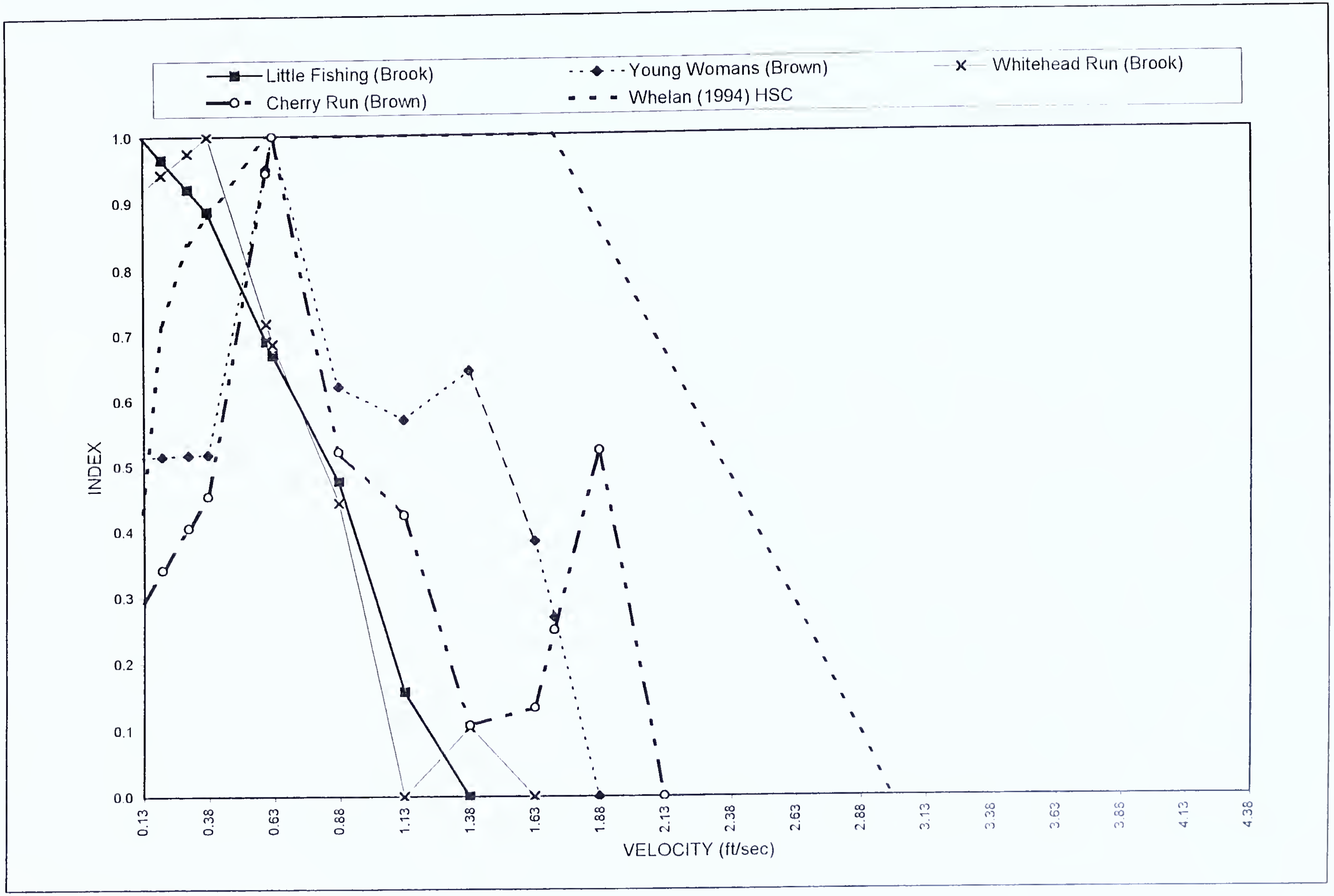

Figure 3.7. Spawning Normalized Modified Forage Indexes for Velocity

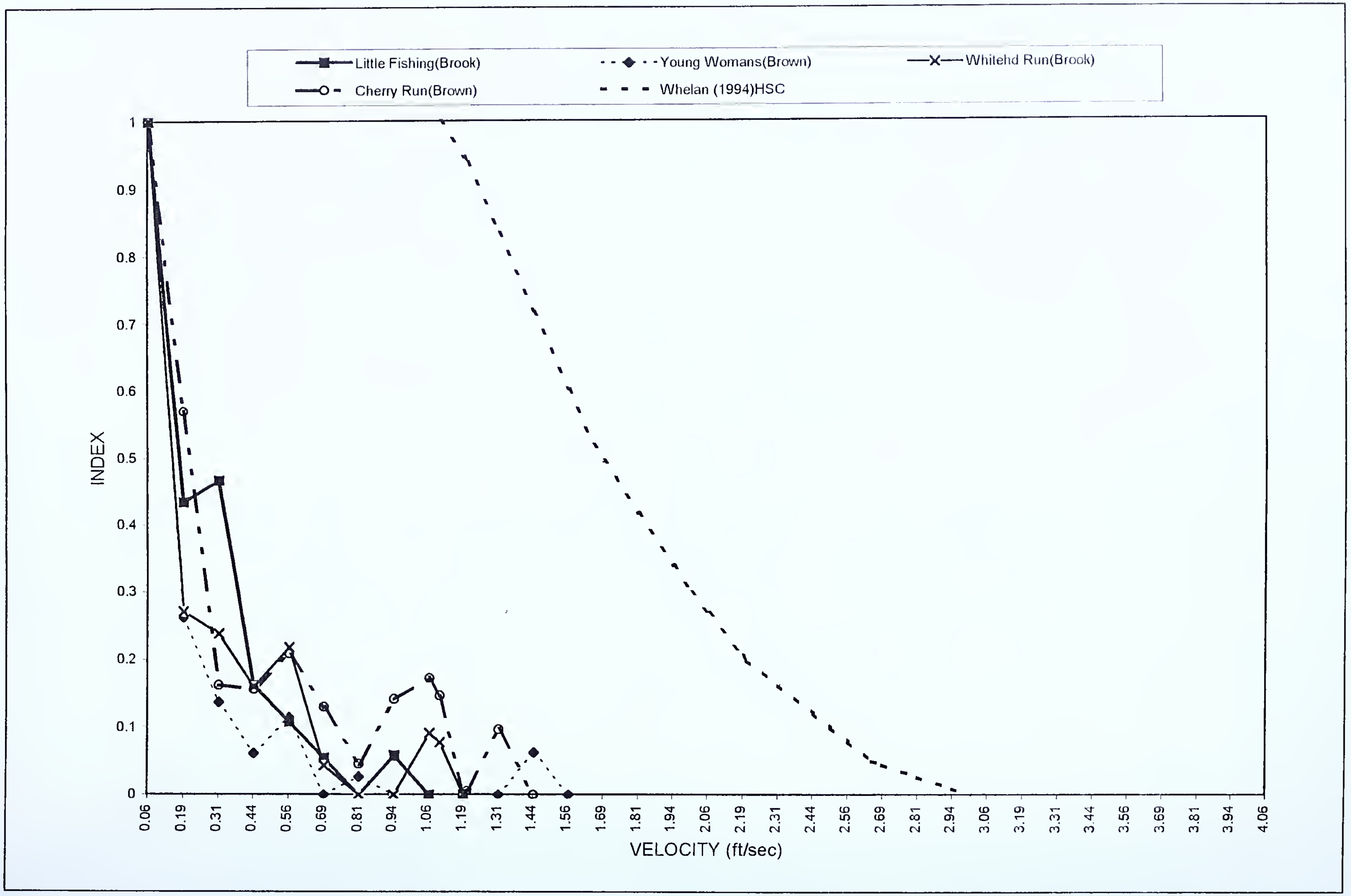

Figure 3.8. Fry Normalized Modified Forage Indexes for Velocity

Table 3.8. Normalized Modified Forage Indexes for Substrate and Cover

Type of Fish/ Name of Stream	Substrate Type			Cover Type				
	1	2	3	1	2	3	4	5
Adult Brook Trout								
Little Fishing Creek	1	0.2	0.6	0	0.5	1	0	0.3
Young Womans Creek	0	1	0.7	0.8	0.8	1	0	0
Whitehead Run	1	0.4	0.5	0	0.6	1	0	0
Adult Brown Trout								
Young Womans Creek	0.9	0.6	1	0.1	0.2	1	0.2	0
Cherry Run	0.5	0.4	1	0.1	0.4	1	0.2	0
Juvenile Brook Trout								
Little Fishing Creek	1	0.6	0.8	0.1	0.4	1	0.2	0.5
Young Womans Creek	1	0.1	0	0.3	0.2	1	0.4	0
Whitehead Run	1	0.6	0.6	0	1	0.9	0	0.1
Juvenile Brown Trout								
Young Womans Creek	0.6	1	0.8	0.1	0.3	1	0.2	0.1
Cherry Run	0.2	0.7	1	0.3	0.8	1	0.8	0
Spawning Brook Trout								
Little Fishing Creek	0	1	0	0.1	0.1	1	0	0.1
Whitehead Run	0.2	1	0	0.3	0.6	1	0	0.5
Spawning Brown Trout								
Young Womans Creek	0	1	0	0.1	0	1	0.2	0
Cherry Run	0	1	0.1	0.6	0.2	1	0.1	0
Fry (Brook/Brown Trout Combined)								
Little Fishing Creek	1	0.3	0.1	0.4	0.3	0.8	0	1
Whitehead Run	1	0.1	0.1	0.5	0.8	0.5	1	0
Young Womans Creek	1	0.6	0.1	0.1	0.2	0.1	0	1
Cherry Run	1	0.4	0.1	0.6	0.4	1	0	0

Note: Substrate and cover type are defined in Table 3.2.

When cover and substrate were analyzed independently, adult brook trout appeared to show strong preference for cover, but little preference for substrate type. Adult brook trout NMFIs for substrate type 1 (silt) ranged from a value of 1 in Little Fishing Creek and Whitehead Run to a value of 0 in Young Womans Creek. The apparent explanation for this difference is that substrate type is unimportant, compared to cover type for the adult life stage. Because no definite pattern could be identified with respect to substrate preference, new adult brook trout substrate/cover HSC were developed based entirely on cover type.

Adult brook trout NMFIs for cover type 1 (no cover) were 0 for both Little Fishing Creek and Whitehead Run. For this reason, cover type 1 was assigned a suitability index of 0 for adult brook trout. Therefore, substrate/cover codes 1.1, 2.1, and 3.1 also were given HSC values of 0. Although the adult brook trout NMFI for cover type 1 in Young Womans Creek was 0.8, this value was not used for new HSC development because adult brown trout appeared to be competing with adult brook trout for cover in this stream. It appears that adult brook trout were being forced into the "no cover" situation as a result of this competition. Brown trout were not found in the section sampled in Little Fishing Creek, and were found in limited numbers in only some parts of Whitehead Run. In Young Womans Creek, adult brown trout seemed to be more closely associated with cover, while adult brook trout appeared to be more closely associated with pool habitat. Adult brook trout would probably have made more extensive use of cover on Young Womans Creek if much of the cover had not already been occupied by adult brown trout.

Adult brook trout NMFIs for cover type 2 (object at least 6 inches high, and with a cross-section horizontal measurement of at least 1 foot) were 0.5 for Little Fishing Creek and 0.6 for Whitehead Run. Therefore, a suitability index of 0.6 was assigned to cover type 2 for adult brook trout. Although the adult brook trout NMFI for cover type 2 in Young Womans Creek was 0.8, this value was not used for HSC development because of possible effects of competition between brook and brown trout previously cited. Selection of the higher value was consistent with the approach used in modifying depth and velocity HSC, as described above.

Cover type 3 (undercut object along bank) had an NMFI of 1 for adult brook trout on all of the streams tested, and was assigned a suitability index of 1.

Only a limited amount of adult brook trout data for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface) were available for the streams sampled. However, if these cover types had been present, adult brook trout probably would have used them in much the same way that they used cover type 2 (object cover). For this reason, the suitability index value assigned to brook trout adults for cover type 2 also was assigned to cover types 4 and 5.

Adult brown trout also appeared to show strong preferences for cover and not for substrate type. Therefore, new adult brown trout substrate/cover HSC also were developed, based solely on cover type. Adult brown trout NMFIs for cover type 1 (no cover) were 0.1 for both Young Womans Creek and Cherry Run. For this reason, cover type 1 was assigned a suitability index of 0.1 for adult brown trout. Adult brown trout NMFIs for cover type 2 (object cover) were 0.2 for Young Womans Creek and 0.4 for Cherry Run. Therefore, a suitability index of 0.4 was assigned to cover type 2 for adult brown trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for adult brown trout in both Young Womans Creek and Cherry Run, and was assigned a suitability index of 1. Cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface) were uncommon. Because these are types of object cover, they were given the same HSC values as cover type 2 (object cover) for brown trout.

As with adults, juvenile brook trout did not appear to show preferences for substrate type, and new substrate/cover HSC were developed based entirely on cover type. Juvenile brook trout NMFIs

for cover type 1 (no cover) were 0.1 for Little Fishing Creek, 0.3 for Young Womans Creek, and 0 for Whitehead Run. Cover type 1 was assigned a suitability index of 0.3 for juvenile brook trout based on the Young Womans Creek value. Although there appeared to be competition between brook and brown trout adults for available cover in Young Womans Creek, it did not appear to be an important factor for juveniles, because both species appeared to use the available habitat in a similar manner.

Juvenile brook trout NMFIs for cover type 2 (object cover) were 0.4 for Little Fishing Creek, 0.2 for Young Womans Creek, and 1 for Whitehead Run. A suitability index of 1 was assigned to cover type 2 for juvenile brook trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for juvenile brook trout in Little Fishing Creek and Young Womans Creek, and a value of 0.9 for juvenile brook trout in Whitehead Run. Cover type 3 was assigned a suitability index of 1 for juvenile brook trout. As described above for brook trout adults, only a limited amount of juvenile brook trout data were available for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface), and these cover types were given the same suitability index values as cover type 2 for juvenile brook trout.

New juvenile brown trout substrate/cover HSC also were developed, based entirely on cover type. Juvenile brown trout NMFIs for cover type 1 (no cover) were 0.1 for Young Womans Creek, and 0.3 for Cherry Run. Cover type 1 was assigned a suitability index of 0.3 for juvenile brown trout.

Juvenile brown trout NMFIs for cover type 2 (object cover) were 0.3 for Young Womans Creek, and 0.8 for Cherry Run. A suitability index of 0.8 was assigned to cover type 2 for juvenile brown trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for juvenile brown trout for both of the streams sampled. Cover type 3 was assigned a suitability index of 1 for juvenile brown trout. Only a limited amount of juvenile brown trout data were available for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface), and these cover types were given the same suitability index values as cover type 2 for juvenile brown trout.

Based on the data for occupied sites, cover appeared to be unimportant for spawning brook trout and brown trout, but substrate was extremely important. Substrate type 2 (coarse sand/gravel) had an NMFI of 1 on all four streams, and was given a suitability index of 1 for both brook and brown trout. Substrate types 1 (silt/fine sand) and 3 (pebbles and larger) were used to a much lesser extent by both species. However, substrate type 1 had an NMFI of 0.2 for Whitehead Run, and therefore, was given a suitability index of 0.2 for brook trout. Substrate type 3 had an NMFI of 0.1 in Cherry Run, and therefore, was given a suitability index of 0.1 for brown trout.

When NMFIs for fry substrate and cover were analyzed separately, substrate was important, but cover usually did not appear to be. Although fry were found in association with cover type 5 (terrestrial vegetation less than 1 foot above water surface) where it was available on Young Womans Creek and Little Fishing Creek, fry may have been selecting more for low velocity water near shore, rather than specifically for cover type 5, which had an NMFI of 1 for both of these streams. Cover type 5 was not present at any of the occupied or unoccupied fry sampling sites on Whitehead Run or Cherry Run. Cover type 5 was assigned a suitability index of 1 in association with all substrate types.

For fry, substrate type 1 (silt/fine sand) had an NMFI of 1 for all four streams. This substrate was given a suitability index of 1 in association with all of the five cover types. When not in association with cover type 5 (terrestrial vegetation less than 1 foot above water surface), substrate type 2 (coarse sand/gravel) had NMFIs ranging from 0.1 to 0.6. Substrate type 2 was given a suitability index of 0.6, except when it was in association with cover type 5, when substrate type 2 was given a value of 1. Substrate type 3 (pebbles and larger) had an NMFI of 0.1 for all streams, so this substrate was given a suitability index of 0.1, except in association with cover type 5, when it was given a value of 1.

In summary, the approach used to develop the new fry substrate/cover HSC recognized the importance of fine substrate, but also put a premium on shoreline habitat with terrestrial vegetation as cover. This approach serves as a check against selecting the flow with the lowest velocity and depth (drought condition) for optimum fry habitat.

3.7.4 Results

The new HSC, based on the NMFIs, are listed in Table 3.9. New depth and velocity HSC are presented graphically as Figures 3.9 through 3.16.

A rerun of the transferability tests on the revised HSC was not performed. The tests would not have been statistically valid, because the transferability test data were used to generate the new HSC.

If the same HSC could be used for brook and brown trout, the amount of time required for PHABSIM modeling could be reduced. To improve modeling efficiency, this option was considered. However, separate HSC were recommended for adults, juveniles, and spawning for the two species, because of the significant differences in NMFIs. NMFIs for brook and brown trout fry were similar, therefore, the same criteria were used for both species for this life stage.

3.8 Conclusions and Recommendations

The new HSC were developed using the best field data available with the resources available for the study. Although all adult and juvenile microhabitat data for the transferability studies were collected in the summer and early fall during daylight hours, microhabitat use may vary seasonally, diurnally, and with the presence of other species competing for the same habitat. Shuler and others (1994) documented differences in microhabitat selection by adult brown trout during the day versus at night. Fausch and White (1981) observed that adult brown trout in the East Branch of the Au Sable River, Michigan, excluded brook trout from preferred resting positions, which were a critical and scarce resource.

Future studies are desirable to test transferability of the newly-developed criteria to other streams, and collect additional data for further HSC refinement. The development of the HSC used in this study assumed that the usability was independent of study region. Also, HSC curves could be further refined by developing separate curves for each study region. Some streams in Pennsylvania have naturally reproducing rainbow trout populations. HSC could be developed for rainbow trout, so that habitat could be modeled and instream flow needs developed for that species. Data collection could be further stratified to consider the season, time of day, and other trout species present.

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study

Adults			Juveniles			Spawning			Fry		
Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC
0	0	0	0	0	0	0	0	0	0	0	0
0.13	0.04	0	0.13	0.11	0.15	0.13	0.4	0.49	0.06	1	1
0.38	0.08	0.09	0.38	0.21	0.15	0.38	1	1	0.19	1	1
0.63	0.26	0.17	0.63	0.64	0.53	0.63	1	1	0.31	1	1
0.88	0.5	0.32	0.88	0.68	0.67	0.88	1	0.58	0.44	1	1
1.13	1	0.62	1.13	1	1	1.13	1	0.46	0.56	1	1
1.38	1	0.83	1.38	1	1	1.38	1	0.33	0.69		
1.63	1	1	1.63	1	0.82	1.63	0	0.26	0.81	0.5	0.5
1.88	1	1	1.88	1	0.64	1.88	0	0.18	0.94	0.2	0.2
2.13	1	1	2.13	0.8	0.27	2.13	0	0	1.06	0.1	0.1
2.38	1	1	2.38	0.75	0.27	2.38	0	0	1.19	0.1	0.1
2.63	1	1	2.63	0.7	0.27	2.63	0	0	1.31	0.1	0.1
2.88	0.45	0.56	2.88	0.5	0.27	2.88	0	0	1.44	0.1	0.1
3.13	0.45	0.56	3.13	0	0.27	3.13	0	0	1.56	0.1	0.1
3.38	0.45	0.56	3.38	0	0	3.38	0	0	1.69	0.1	0.1
3.63	0.45	0.56	3.63	0	0	3.63	0	0	1.81	0.1	0.1
3.88	0.45	0.56	3.88	0	0	3.88	0	0	1.94	0.1	0.1
4.13	0.45	0.56	4.13	0	0	4.13	0	0	2.06	0	0
4.38	0.45	0.56	4.38	0	0	4.38	0	0	2.19	0	0
4.63	0.45	0.56	4.63	0	0	4.63	0	0	2.31	0	0
4.88	0.45	0.56	4.88	0	0	4.88	0	0	—	0	0
5.13	0.45	0.56	5.13	0	0	5.13	0	0	5.94	0	0

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study—Continued

Adults			Juveniles			Spawning			Fry		
Velocity (ft/sec)	Brook Trout HSC	Brown Trout HSC	Velocity (ft/sec)	Brook Trout HSC	Brown Trout HSC	Velocity (ft/sec)	Brook Trout HSC	Brown Trout HSC	Velocity (ft/sec)	Brook Trout HSC	Brown Trout HSC
0	1	0.66	0	1	0.58	0	1	0.5	0	1	1
0.13	1	0.75	0.13	1	0.64	0.13	1	0.51	0.06	1	1
0.38	1	0.92	0.38	1	0.76	0.38	1	0.52	0.19	0.6	0.6
0.63	0.92	1	0.63	1	1	0.63	0.69	1	0.31	0.5	0.5
0.88	0.84	1	0.88	1	1	0.88	0.48	0.65	0.44	0.2	0.2
1.13			1.13	0.71	0.74	1.13	0.16		0.56	0.2	0.2
1.38		0.9	1.38			1.38	0.1	0.65	0.69	0.1	0.1
1.63	0.5		1.63	0.48		1.63	0	0.39	0.81	0.1	0.1
1.88	0.43		1.88		0.7	1.88			0.94	0.1	0.1
2.13	0.25	0.79	2.13	0.19		2.13	0	0	1.06	0.1	0.1
2.38	0.2	0.5	2.38		0.39	2.38			1.19	0.1	0.1
2.63			2.63	0	0.13	2.63			1.31	0.1	0.1
2.88			2.88	0	0	2.88			1.44	0.1	0.1
3.13	0.14		3.13			3.13			1.56	0	0
3.38	0	0.5	3.38			3.38			1.69		
3.63		0	3.63			3.63			1.81		
3.88			3.88			3.88			1.94		
4.13			4.13			4.13			2.06		
4.38			4.38			4.38			2.19		
4.63			4.63			4.63			2.31		
4.88			4.88			4.88			2.44		
5.13			5.13			5.13			2.56		
5.38			5.38			5.38			2.69		
5.63			5.63			5.63			—		
5.88	0	0	5.88	0	0	5.88	0	0	4.06	0	0

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study—Continued

Adults			Juveniles			Spawning			Fry		
Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC
1.1	0	0.1	1.1	0.3	0.3	1.1	0.2	0	1.1	1	1
1.2	0.6	0.4	1.2	1	0.8	1.2	0.2	0	1.2	1	1
1.3	1	1	1.3	1	1	1.3	0.2	0	1.3	1	1
1.4	0.6	0.4	1.4	1	0.8	1.4	0.2	0	1.4	1	1
1.5	0.6	0.4	1.5	1	0.8	1.5	0.2	0	1.5	1	1
2.1	0	0.1	2.1	0.3	0.3	2.1	1	1	2.1	0.6	0.6
2.2	0.6	0.4	2.2	1	0.8	2.2	1	1	2.2	0.6	0.6
2.3	1	1	2.3	1	1	2.3	1	1	2.3	0.6	0.6
2.4	0.6	0.4	2.4	1	0.8	2.4	1	1	2.4	0.6	0.6
2.5	0.6	0.4	2.5	1	0.8	2.5	1	1	2.5	1	1
3.1	0	0.1	3.1	0.3	0.3	3.1	0	0.1	3.1	0.1	0.1
3.2	0.6	0.4	3.2	1	0.8	3.2	0	0.1	3.2	0.1	0.1
3.3	1	1	3.3	1	1	3.3	0	0.1	3.3	0.1	0.1
3.4	0.6	0.4	3.4	1	0.8	3.4	0	0.1	3.4	0.1	0.1
3.5	0.6	0.4	3.5	1	0.8	3.5	0	0.1	3.5	1	1

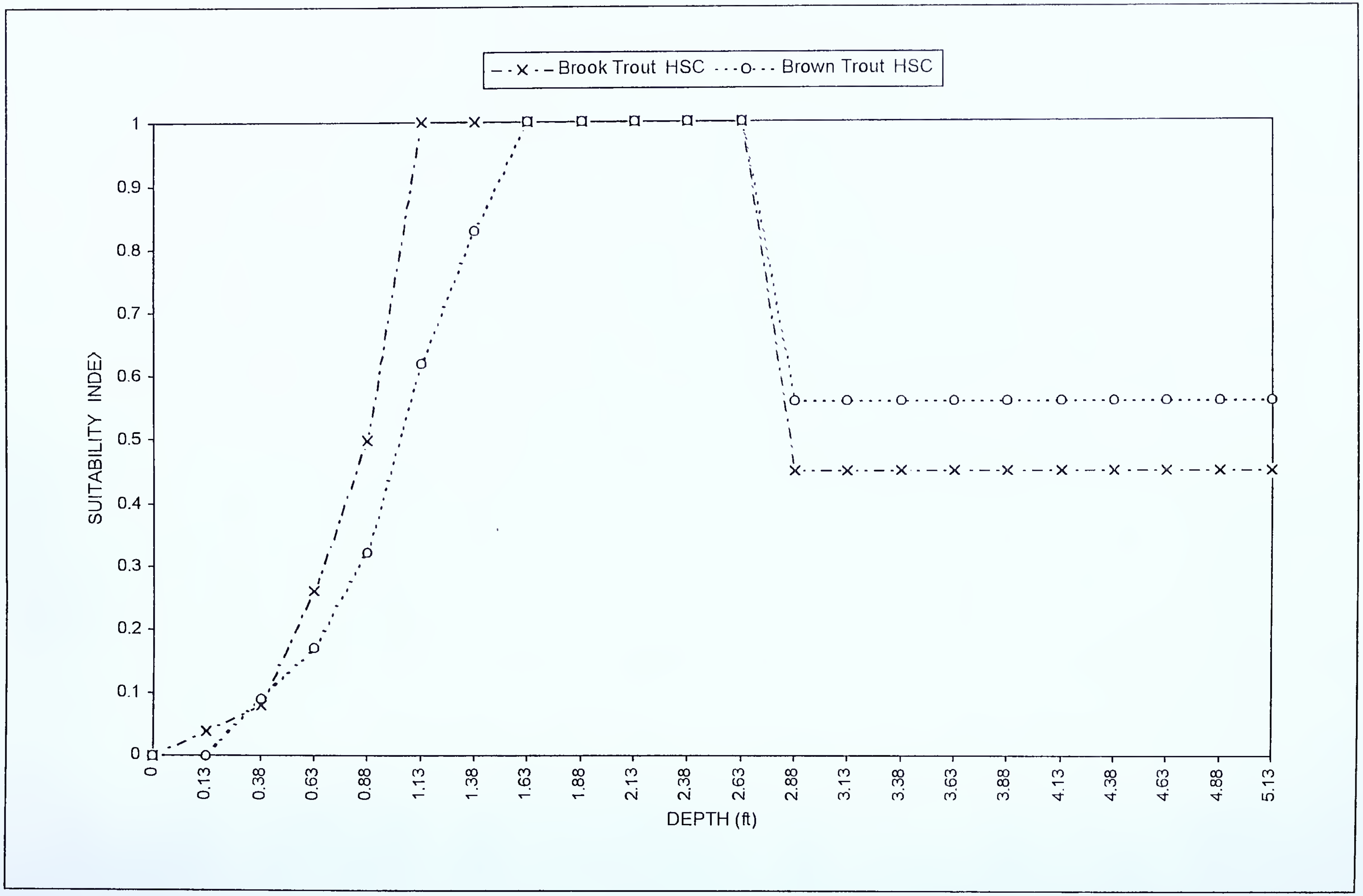

Figure 3.9. Adult Habitat Suitability Criteria for Depth

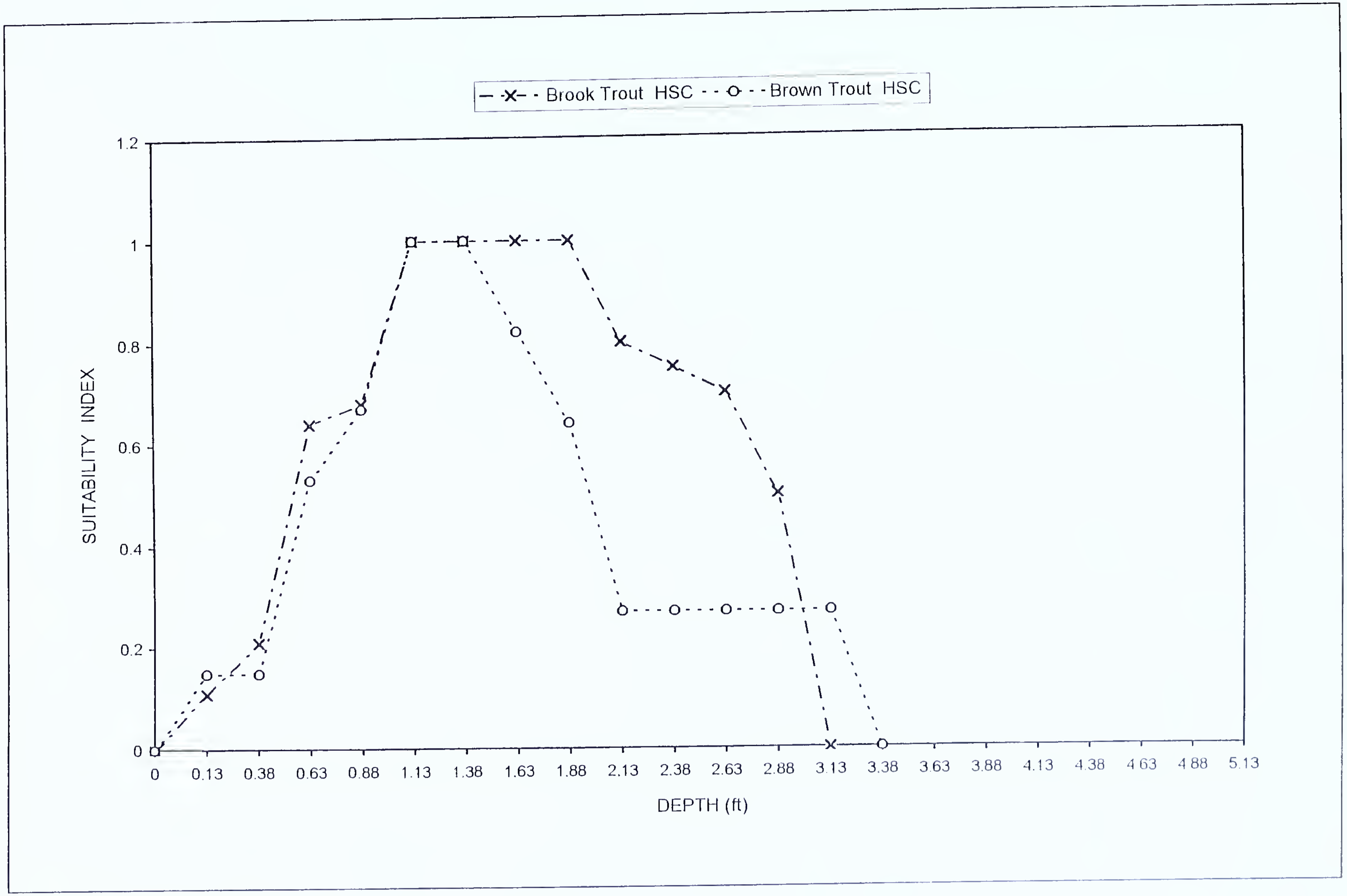

Figure 3.10. Juvenile Habitat Suitability Criteria for Depth

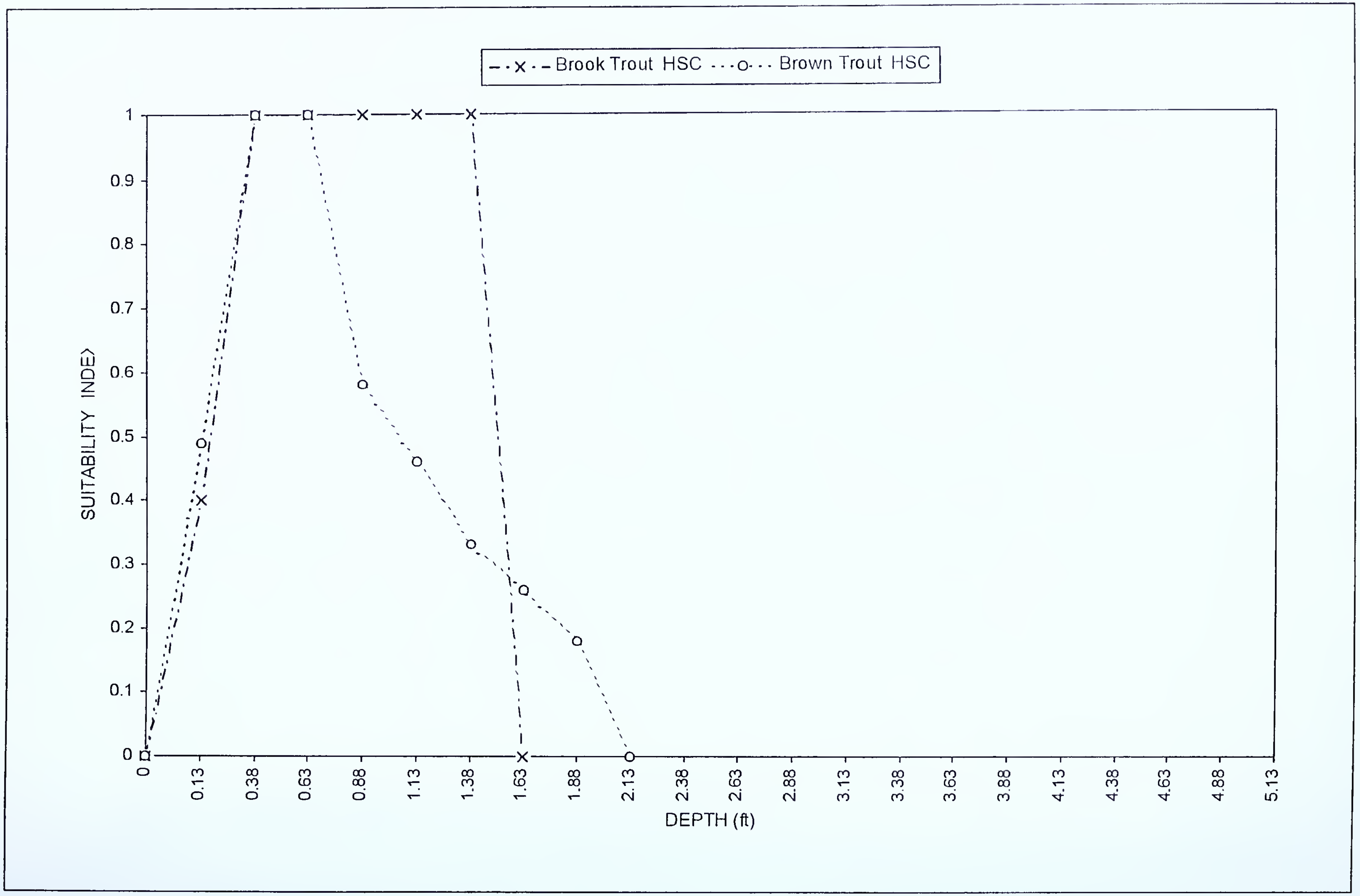

Figure 3.11. Spawning Habitat Suitability Criteria for Depth

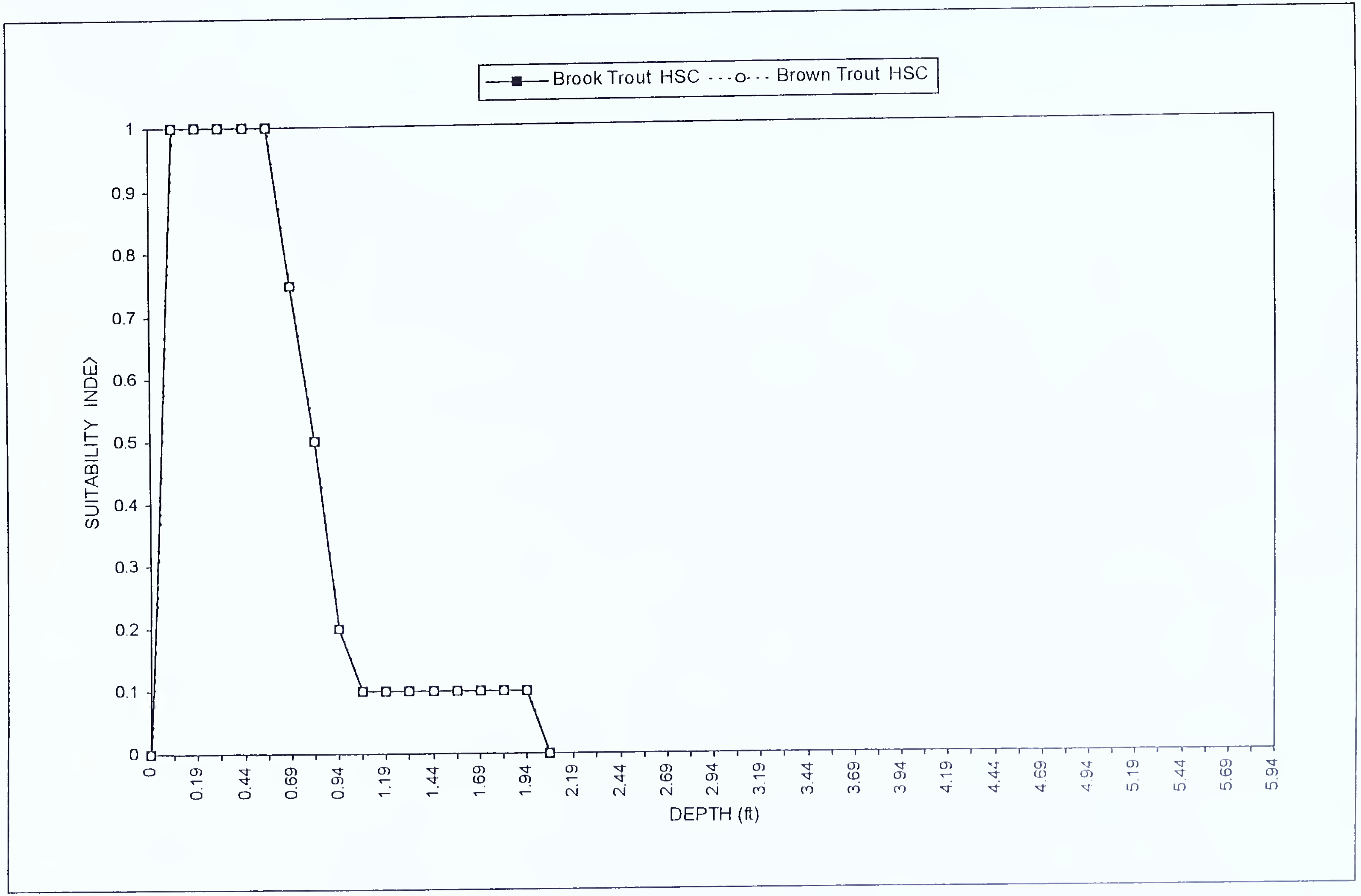

Figure 3.12. Fry Habitat Suitability Criteria for Depth

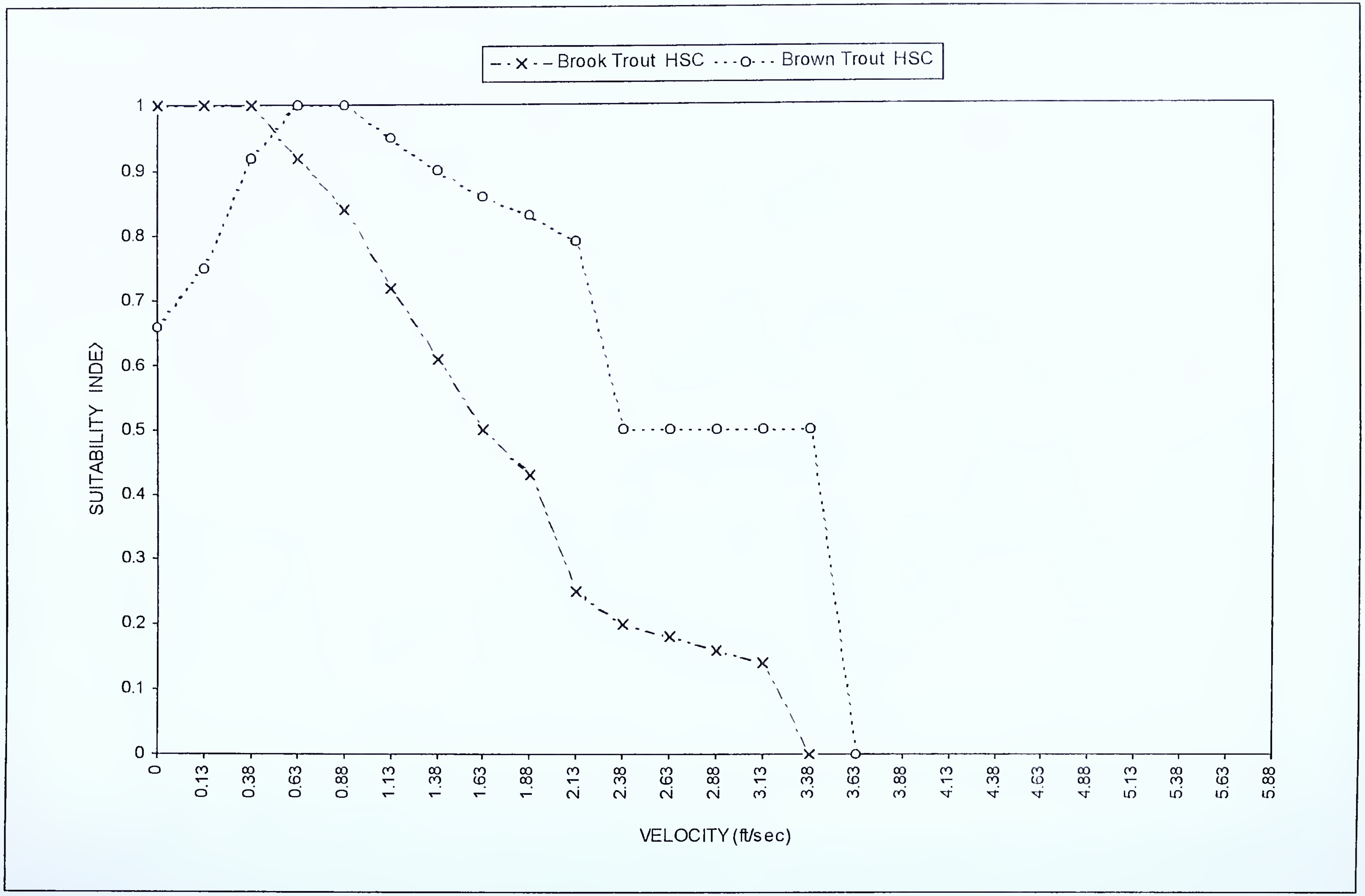

Figure 3.13. Adult Habitat Suitability Criteria for Velocity

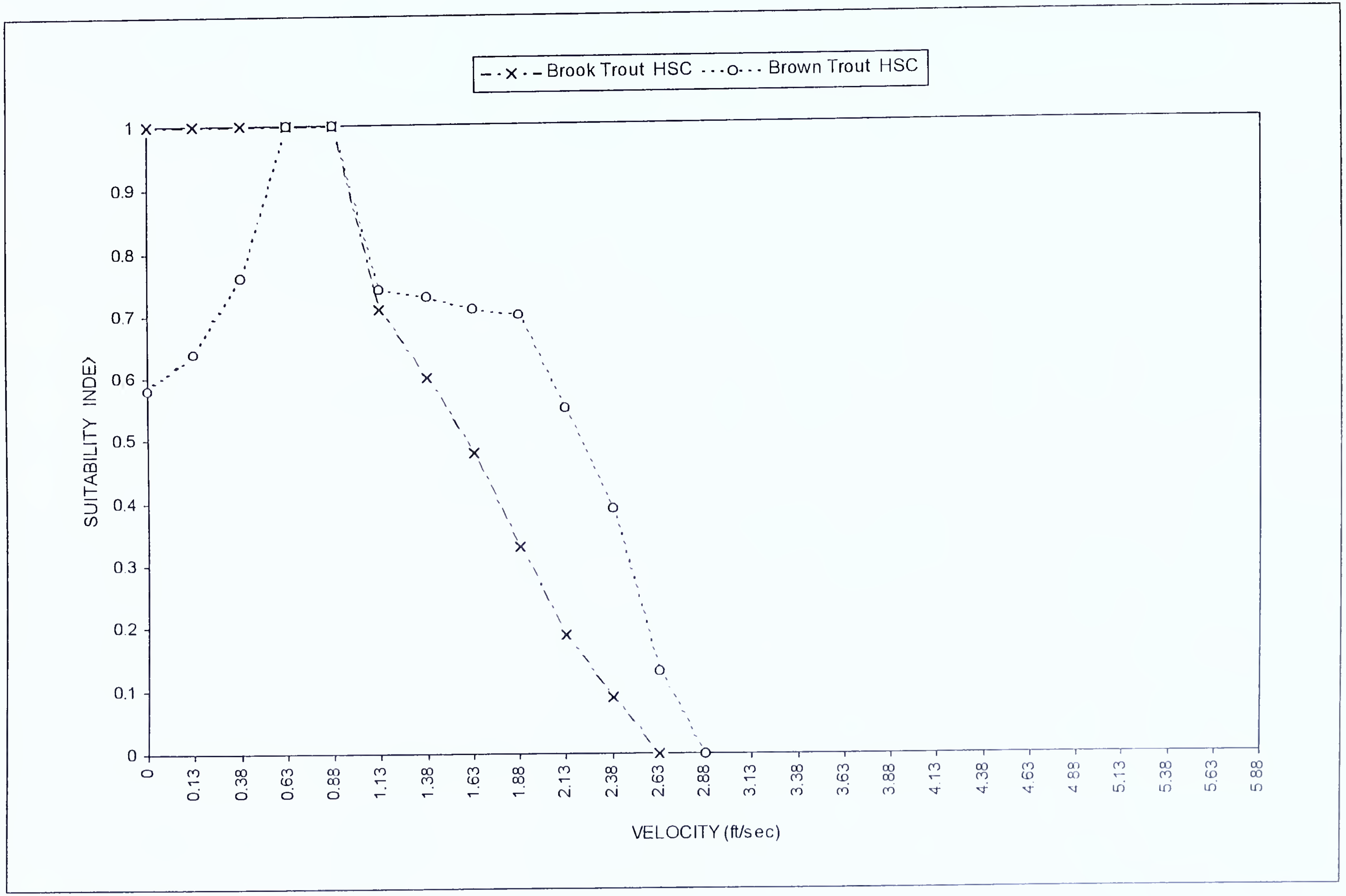

Figure 3.14. Juvenile Habitat Suitability Criteria for Velocity

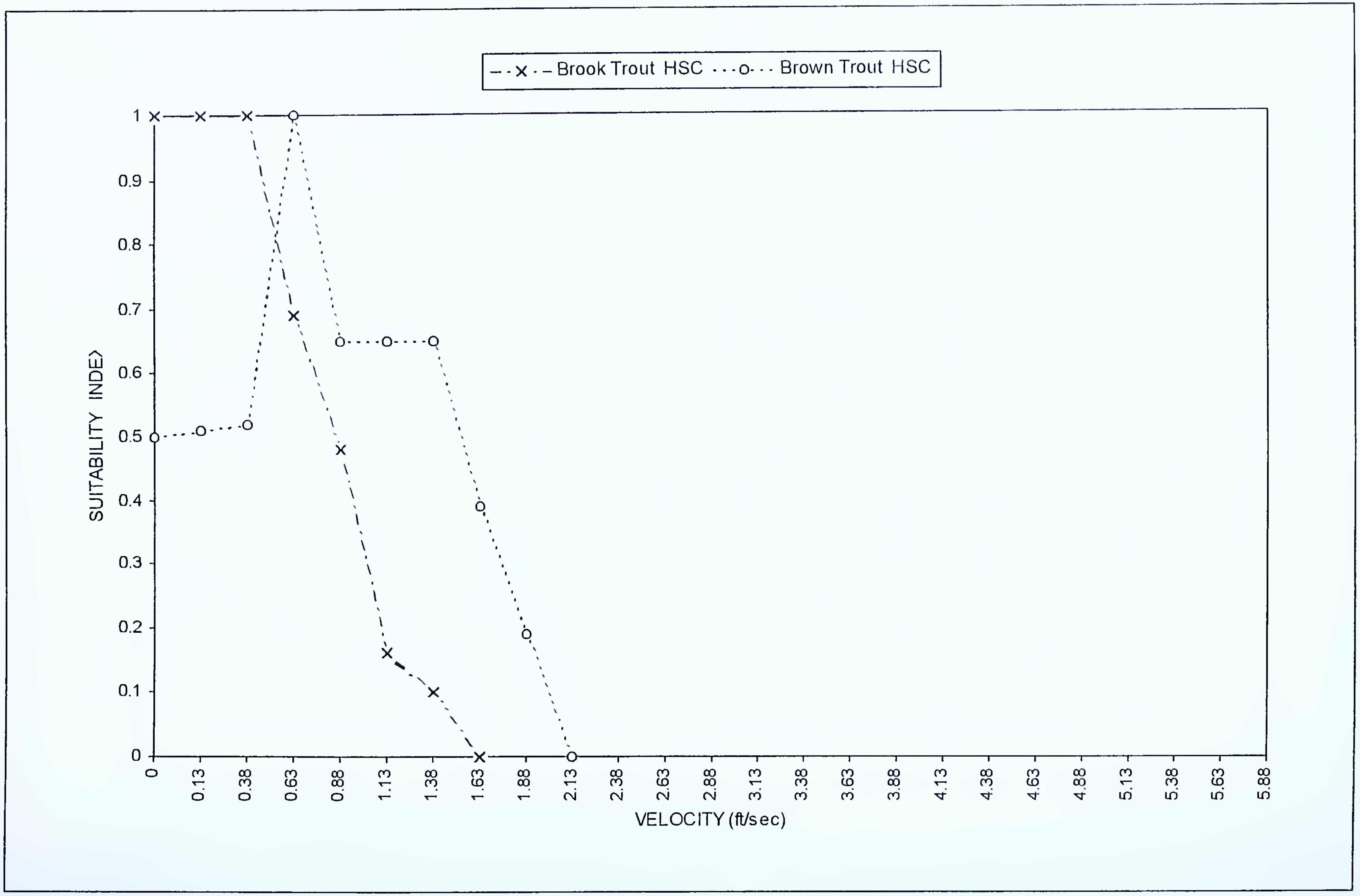

Figure 3.15. Spawning Habitat Suitability Criteria for Velocity

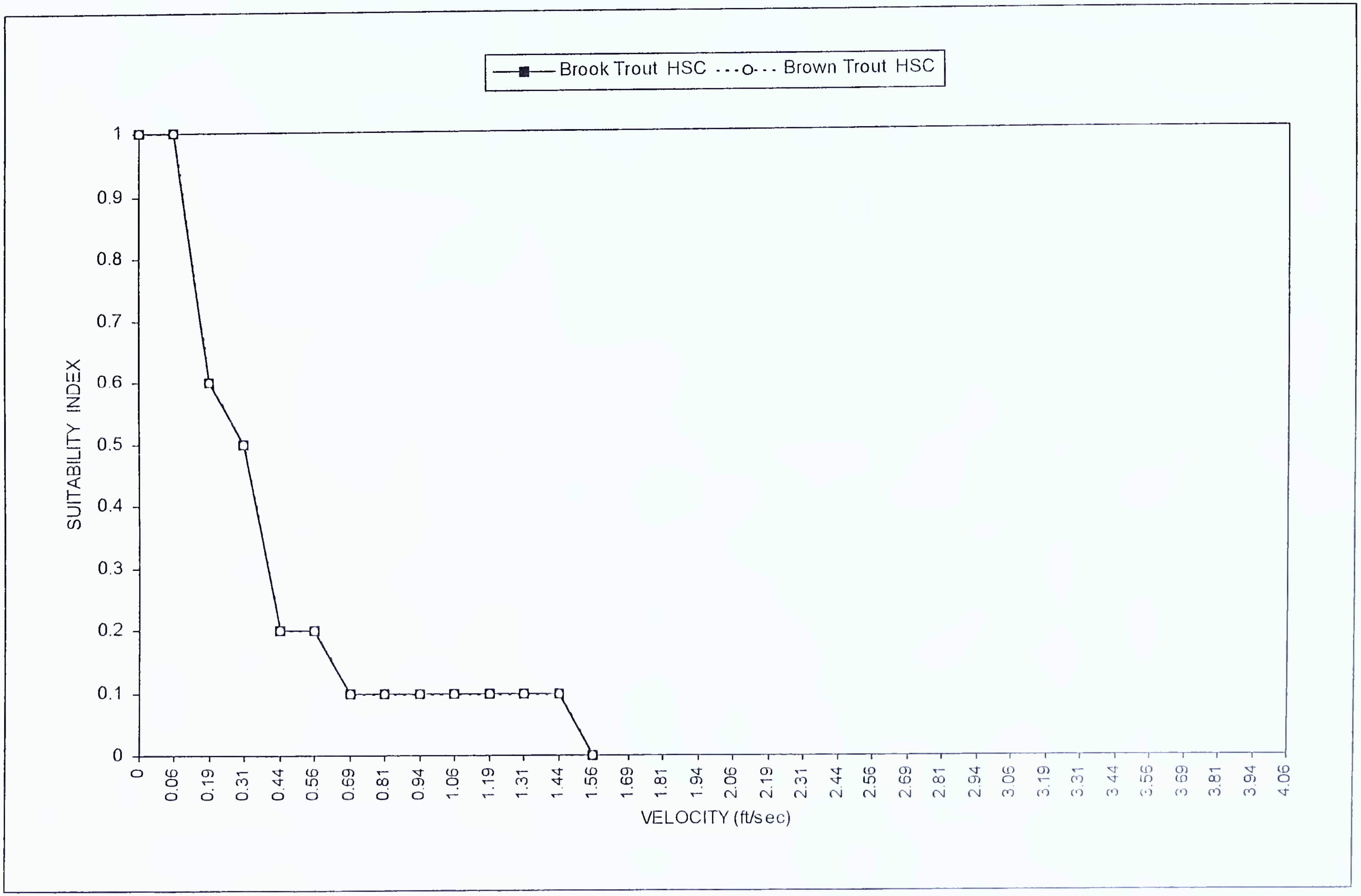

Figure 3.16. Fry Habitat Suitability Criteria for Velocity

4.0 SELECTION OF STUDY STREAMS

4.1 Overview

The procedure for selecting study streams involved developing a stream database for Pennsylvania streams, statistical analysis to determine if streams could be classified according to length, rather than slope, further statistical analysis to determine an appropriate length increment for study segments, and random selection of streams in each class to develop a list of potential study streams for field verification. Maryland streams were selected from lists prepared from existing information.

4.2 Development of the Stream Database for Pennsylvania Streams

The stream database was developed by linking the PFBC stream inventory data file with the Pa. DEP stream file, and editing the resulting file. This database was then used for statistical analyses of stream drainage area, slope, and length, and to select study streams.

PFBC has inventoried, and continues to inventory, cold water streams to collect data for management of fishery resources (J. Arway, PFBC, oral communication). Each stream surveyed is divided into one or more sections based on changes in slope, land use, or type of fishery (cold water/warm water). At least 10 percent of the total stream length and at least 1,000 ft of stream are surveyed.

PFBC provided the available inventory data for 3,997 named and unnamed stream sections in a computer file. The data file included all streams where trout reproduction had previously been documented, and unsurveyed streams where reproduction was considered likely, based on the characteristics of other reproducing trout streams in the area. The file included: stream name; stream section number; state water plan subbasin and watershed; county; area fisheries manager; area surveyed (acres and hectares); section length (miles and kilometers); descriptive upstream limit; descriptive downstream limit; whether the section was stocked with trout; stream management classification; and whether the section had been surveyed. Some streams had multiple sections included in the database. Eighty-five unnamed stream sections were deleted from the PFBC file, because they could not be located on a map.

The remaining 3,912 named stream sections were linked to a computer file of the Pennsylvania Gazetteer of Streams (Shaw and Wetzel, 1989) by adding a stream code to the PFBC file. The Gazetteer includes: stream code; stream name; location of the stream mouth (at or near a populated location); latitude and longitude of the mouth of the stream; county; quadrangle map; drainage area; and river-mile of the mouth of the stream (defined as distance to the mouth of the stream, along the stream to which it is tributary). Some named stream sections in the PFBC file were not assigned stream codes, because the available information was insufficient to differentiate between similarly named streams in the same state water plan watershed and county. Other streams were not assigned a stream code, because the stream name in the PFBC file did not match any named stream in the Gazetteer file. The stream code was used to link the PFBC file with the Pa. DEP stream file. This link allowed the determination of the location and amount of withdrawals or wastewater discharges.

Each stream section shown in the linked files was assigned to the appropriate study region using the map of physiographic provinces and sections in Pennsylvania (Pa. Department of Environmental Resources, 1989), and the limestone/freestone classification for streams in the Ridge and Valley Province. The study region boundaries were overlaid on a Pennsylvania stream map (Ings and Simmons, 1991). Then the computer file was sorted by county and quadrangle map, and visually matched to the stream map with the overlay. For the Piedmont Province in Pennsylvania, streams were assigned to one of the

physiographic sections (Piedmont Upland, Piedmont Lowland, and Gettysburg-Newark Lowland), on the assumption that geologic differences among these sections would result in differences in the streams.

Streams in the Ridge and Valley physiographic province were identified as limestone or freestone, and the identification was added to the file. Streams were classified as limestone if they were correspondingly identified by Shaffer (1991), or if they had a total alkalinity greater than 70 mg/L, as shown by PFBC (1994). A map of limestone rocks also was constructed, based on the Atlas of Pennsylvania's Mineral Resources (Pa. Department of Internal Affairs, 1967) and used to validate the list of limestone streams.

For the Ridge and Valley Freestone study region, stream slope was determined for a sample of 64 stream sections and added to the file. The slope was defined as the elevation difference, computed from the contour elevation at the upper and lower limits, divided by the distance along the stream between those limits. Elevations and distances were determined from USGS quadrangle maps.

The PFBC file was manipulated to combine stream sections for streams with multiple sections and develop cumulative lengths and corresponding location descriptions. A summary of streams in the four study regions is shown in Table 4.1. This file contained 553 Ridge and Valley Freestone streams, including the 64 streams for which slope was determined. The file included a few streams with drainage areas in the range from 100 to 200 square miles. The file was used to determine the frequency of stream lengths, and whether there was any correlation between stream slope and stream length, as described in section 4.3. The file also was used to select potential study streams, as described in section 4.4.

Table 4.1. Number of Trout Streams in Each Study Region

Study Region	Number of Study Streams
Ridge and Valley Limestone	119
Ridge and Valley Freestone	553
Unglaciated Plateau	1,781
Piedmont Upland	45
Total	**2,498**

4.3 Slope–Length Relationship and Segment Length Criteria

Stream slope is a major factor affecting channel morphology and fishery habitat, because it directly affects depth and velocity, and indirectly affects substrate. For that reason, streams should be categorized according to slope. Because the determination of slope is a time-consuming process for such a large number of streams, the relationship between slope and length was investigated to determine whether length could be used as a surrogate for slope.

As discussed in section 4.2, slope was determined for 64 streams in the Ridge and Valley Freestone study region. A simple correlation between length and slope for these streams showed a moderately strong relationship (correlation coefficient of 0.46), with increasing length associated with decreasing slope. Since the relationship was reasonably strong, length was used as a surrogate for slope to classify streams.

Because there also is a strong correlation between drainage area and stream length, drainage area and stream length frequency analyses were used to establish classes of streams within a study region. First, the drainage area frequency was analyzed for all the reproducing trout streams in a study region to determine the percentage of streams with drainage areas less than 10 square miles. Then stream length frequency analyses for the same streams for different assumed segment lengths were used to determine the length increment that included approximately the same percentage of streams in the first increment of the frequency plot.

The drainage area frequency analysis (Figure 4.1) for 441 reproducing trout streams in the Ridge and Valley Freestone study region showed 77 percent of these streams have a drainage area less than 10 square miles. Stream length frequency analysis for the 64 streams used in the length/slope correlation analysis for this region showed (Figure 4.2) stream length increments of 5 miles resulted in 78 percent of the streams being within the first increment of the frequency plot. This segment length was adopted for classifying streams within the Ridge and Valley Freestone study region, under the assumption that streams within different length increments of five miles would have different slopes. Differences in slope, mesohabitat types, and other physical features for streams in different length classes were observed visually during field data collection.

This process was repeated for the Ridge and Valley Limestone, Unglaciated Plateau, and Piedmont Upland study regions. The optimum stream length for each of these regions was either equal to, or greater than, the increment determined for the Ridge and Valley Freestone region. A five-mile stream length increment was used for all the study regions to standardize field location procedures, and to eliminate segment length as a variable when comparing study results among different study regions.

4.4 Study Stream Selection Procedure and Results

Study streams were selected in three stages. The first stage was selecting potential study streams from USGS quadrangle maps to prepare a list for use in field selection. The second stage was conducting field verifications to determine if there were any reasons (access, man-made influences, absence of reproducing trout, or poor water quality) that the stream was unusable for this study. The third stage was deleting certain streams, because of problems experienced during mathematical modeling. The first two stages are described in this section, and the third stage is discussed in section 5.6.

Streams in Pennsylvania were selected from the list of reproducing trout streams in each study region, prepared as described in section 4.2. Reproducing trout streams in the Maryland Piedmont Upland study region were selected from a list prepared by Md. DNR staff from a report prepared by Steinfelt (1991). In the Ridge and Valley Freestone and Unglaciated Plateau study regions, only streams that supported reproducing trout populations for their entire length were selected. In the Ridge and Valley Limestone region, the limits of the stream reach that was underlain by limestone rocks and supported reproducing trout populations were easily defined from available data, and used to define study limits.

No data are available to show the variability in habitat among the trout streams in the study regions, and therefore, there was no statistical basis for determining the number of stream segments necessary to provide an appropriate level of accuracy. Considering the expected variability in the WUA versus flow relationships within a study region, and the resources available for the study, a total of 30 stream segments for each study region was assumed to provide an appropriate level of accuracy.

For the Ridge and Valley Limestone study region, the locations of the trout streams were verified, and PFBC files were reviewed to determine whether the limits of the limestone portion of the stream had

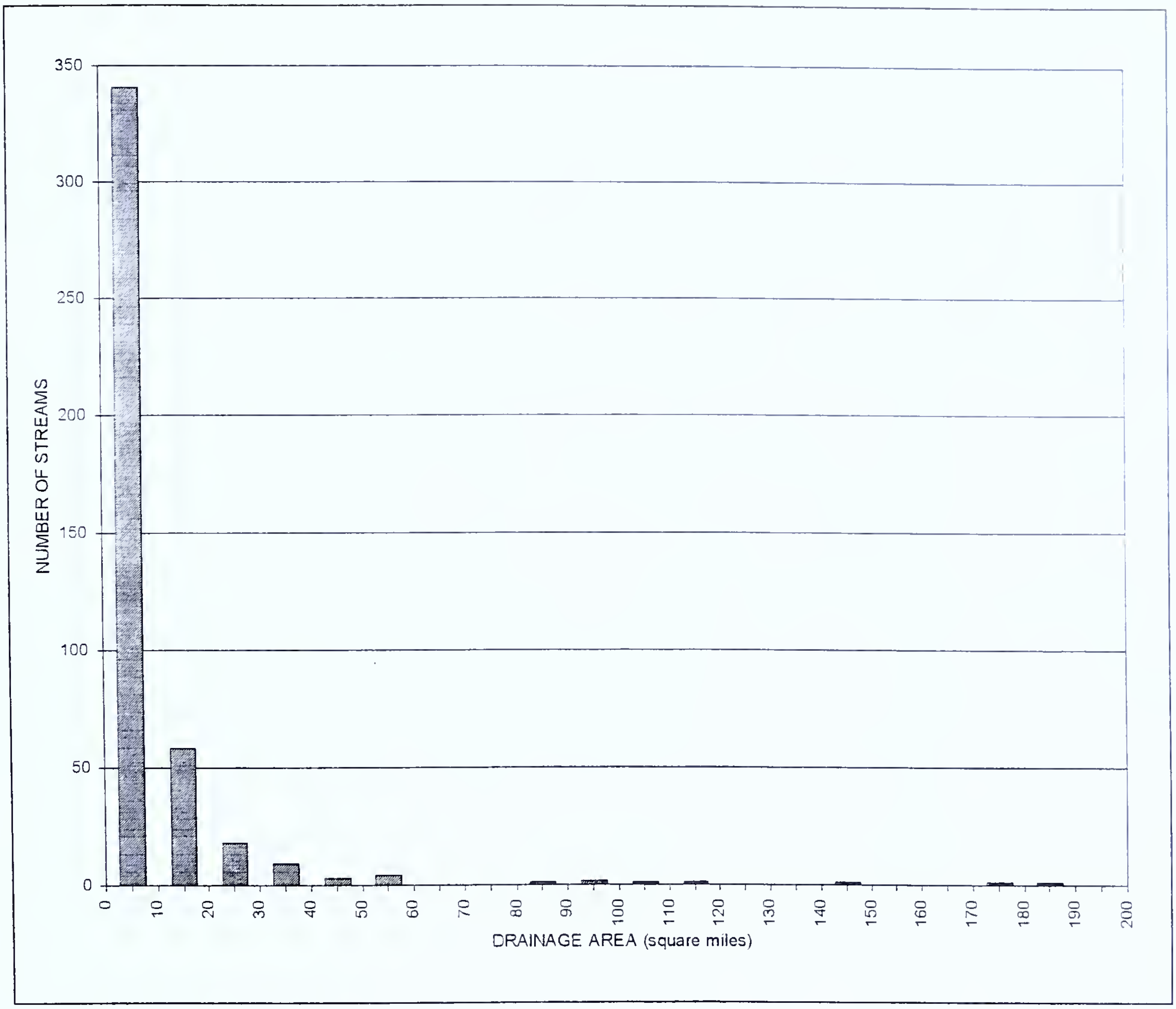

Figure 4.1. Frequency Distribution of Stream Drainage Area in Ridge and Valley Freestone Region

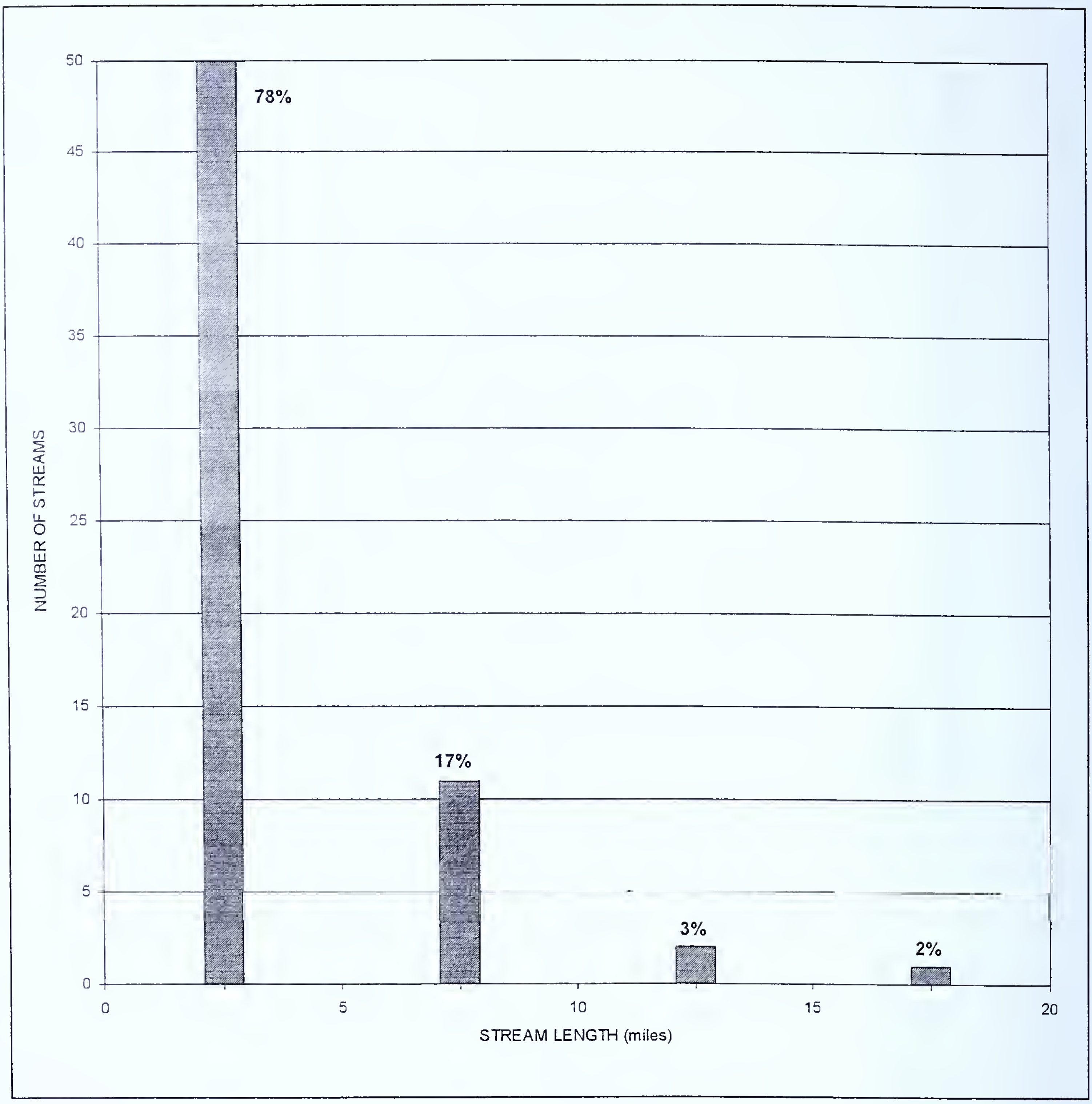

Figure 4.2. Frequency Distribution of Stream Length in Ridge and Valley Freestone Region

been clearly identified, based on total alkalinity exceeding 70 mg/L. Then inaccessible streams, as determined from USGS quadrangle maps, were deleted from the overall list. These steps resulted in a population of 34 streams and 53 stream segments, from which limestone streams were selected.

For all the study regions, streams and stream segments were selected using a stratified random sampling design. The boundaries of each study region were overlaid on a grid of all USGS 7.5-minute quadrangle maps for the states of Pennsylvania and Maryland. Quadrangle maps were retained for site selection if the map was entirely within one study region, and included the mouth of at least one reproducing trout stream.

Then the population of topographic maps for each study region was divided into groups. For the Unglaciated Plateau and Ridge and Valley Limestone and Freestone study regions, the population of maps was divided into three groups of approximately equal surface area. In the Piedmont Upland study region, the maps in the study area were divided into two groups, based on state boundaries. Because 65 percent of the reproducing trout streams in the Piedmont Upland study region were located in Maryland and 35 percent in Pennsylvania, this same proportion of sites was selected from the populations included in the two groups for that region.

To select streams and stream segments for each study region, each quadrangle within each map group (Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau, Piedmont Upland) was numbered. Then a table of random numbers was used to select quadrangles, with the restriction that only quadrangles containing at least two stream segments were used (e.g., two or more one-segment streams, or at least one two-, three-, or four-segment stream). This restriction was intended to minimize travel time for the field crews. This restriction was not applied in selecting limestone streams, because of the limited number of quadrangles available, and because often only one stream was available per map.

The streams within each selected quadrangle were listed in alphabetical order, numbered consecutively, and similarly selected using a random numbers table. This process was continued until ten segments were selected from each group of maps, with the stipulation that the final proportion of streams of the various segment sizes matched as closely as possible the proportion of streams with those same segment sizes in the population of streams in the respective region. Thus, if 80 percent of all the trout streams in the Unglaciated Plateau study region were one-segment streams, approximately 80 percent of the streams selected for that region also were one-segment streams.

In addition, several alternate quadrangles and streams were randomly selected for each region in anticipation that other factors (e.g., access to private property not allowed, excessive development, or water quality or physical habitat constraint), might render selected streams unusable.

As each stream was selected from the quadrangle, the accessibility of that stream by road was reviewed on the map, and inaccessible streams were deleted.

Thirty stream segments were selected for the Piedmont Upland study region; however, available funds allowed inclusion of only 12 stream segments (all in Maryland) in this study. Additional streams in all the Piedmont study regions should be studied to develop instream flow guidelines for those regions.

The number of potential study streams in each study region was tabulated from the stream database, and the numbers of streams in each segment class were determined. The number of segments was determined by dividing the length of the stream reach by the maximum allowable segment length (5 miles), and rounding to the next higher integer (for example, an 8-mile stream would have two segments). The segment length for each stream was determined by dividing the reach length by the number

of stream segments. For example, a stream with a study length of 13 miles, and a maximum allowable segment length of 5 miles, would have three segments, and an actual segment length of 4.33 miles.

Lists of potential study streams are shown in Tables 4.2 through 4.5. A summary of the numbers of potential study streams, both primary and alternate, by segment class, is shown in Table 4.6 for each region.

These lists of potential study streams were furnished to the field crews for stream reconnaissance and final study stream selection in the field. For the Ridge and Valley limestone study region, the list included a description of the limits of each stream having a reproducing trout population, and the length of that reach.

Table 4.2. USGS Quadrangles and Streams Randomly Selected From the Unglaciated Plateau Study Region
(Final quadrangles and streams selected after field reconnaissance are shown in bold.)

USGS Quad	County	Stream	Trout Species (*=Dominant)	Length (miles)
Northeast				
Cameron	Cameron	**Tannery Hollow Run**	Brook	2.0
	Cameron	**Whitehead Run**	Brook*, Brown	2.5
	Cameron	McKinnon Branch		6.6
	Cameron	Hunts Run		7.2
Black Moshannon	Centre	**Benner Run**	Brook*, Brown	3.7
	Centre	**Meyers Run**	Brook	0.9
	Centre	Six Mile Run		9.5
Mt. Jewett	McKean	Sicily Run		3.2
	Elk	Lanigan Branch		3.5
Keating	Clinton	Upper Stimpson Run		1.2
	Clinton	Wistar Run		2.3
	Clinton	Grass Flats Run		2.2
	Clinton	**Mill Run**	Brook	1.7
Norwich	McKean	**Strange Hollow**	Brook	3.1
	McKean	**Lyman Run**	Brook	2.1
	McKean	Havens Run		1.9
	McKean	E. Br. Potato Creek		4.5
Glen Richey	Clearfield	Potts Run		9.4
	Clearfield	Lt. Clearfield Creek		13.9
	Clearfield	**Dunlap Run**	Brook	2.7
	Clearfield	Hogback Run		2.5
	Clearfield	Camp Hope Run		2.5
Hazel Hurst	McKean	Stanton Brook		1.8
	McKean	**Bloomster Hollow**	Brook	3.5
	McKean	**Warner Brook**	Brook	3.7
	Elk	Seven Mile Run		3.3
Northwest				
Russell City	Elk	**E. Br. Spring Creek**	Brook, Brown	11.5
	Elk	Wolf Run		4.7
	Elk	Coon Run		3.0
	Forest	Bogus Run		2.3
Cooksburg	Forest	**Cherry Run**	Brook	3.2
	Jefferson	**Seaton Run**	Brook	2.4
	Forest	Toms Run		5.9
Kennerdell	Venango	**Lower Two Mile Run**	Brook*, Brown	7.9
	Venango	Bullion Run		4.5
	Venango	Dennison Run		2.7
DuBois	Jefferson	Sugar Camp Run		1.9
	Clearfield	**Beech Run**	Brook	4.5
Falls Creek	Jefferson	**McEwen Run**	Brook	3.1
	Jefferson	**Rattlesnake Run**	Brook	4.9
	Jefferson	Rattlesnake Creek		7.9
	Jefferson	Walburn Run		2.0
Marienville W.	Forest	Bearpen Run		3.1
	Forest	Ellsworth Run		1.6

Table 4.2. USGS Quadrangles and Streams Randomly Selected From the Unglaciated Plateau Study Region—Continued
(Final quadrangles and streams selected after field reconnaissance are shown in bold.)

USGS Quad	County	Stream	Trout Species (*=Dominant)	Length (miles)
South				
Irvona	Clearfield	N. Witmer Run		6.2
	Clearfield	Davidson Run		1.5
	Clearfield	Comfort Run		3.4
Beaverdale	Cambria	Otto Run		5.8
Vintondale	Indiana	**Findley Run**	Brook*, Brown	4.9
	Cambria	**Red Run**	Brook	2.5
Central City	Somerset	Calendars Run		2.0
	Somerset	Clear Run		2.5
Colver	Cambria	Dutch Run		9.7
Confluence	Somerset	**Coke Oven Hollow**	Brook	3.0
	Somerset	Smith Hollow		4.1
	Somerset	**Whites Creek**	Brook	9.6
	Somerset	**McClintock Run**	Brook	4.6
	Somerset	Paddytown Hollow		4.1
Kingwood	Somerset	Cranberry Glade Run		3.7
	Somerset	Harbaugh Run		2.7
	Somerset	Sandy Run		6.0
	Somerset	**Fall Creek**	Brook	5.2
Burnside	Indiana	**Cush Creek**	Brown	7.9
	Indiana	Beaver Run		5.3

Table 4.3. USGS Quadrangles and Streams Randomly Selected From the Ridge and Valley Freestone Study Region
(Final quadrangles and streams selected after field reconnaissance are shown in bold.)

USGS Quad	County	Stream	Trout Species (*=Dominant)	Length (miles)
Northeast				
Shickshinny	Luzerne	Black Ash Run		1.9
	Luzerne	Kitchen Creek		7.2
Berwick	Luzerne	**Salem Creek**	Brook*, Brown	4.5
	Luzerne	**Wapwallopen Creek**	Brown*, Brook	22.4
Danville	Columbia	**Mugser Run**	Brown	7.8
	Montour	Kase Run		4.3
Bloomsburg	Columbia	**Green Creek**	Brown	12.0
	Columbia	Stony Brook		4.0
Stillwater	Columbia	**E. Br. Raven Creek**	Brook	2.9
	Luzerne	W. Br. Ash Creek		3.8
	Luzerne	Bell Creek		3.1
Delano	Schuylkill	Neifert Creek		3.8
	Schuylkill	Lofty Creek		3.8
Northwest				
Williamsport SE	Union	**Mile Run**	Brook	1.2
	Lycoming	Bear Trap Hollow		1.6
	Union	**Sand Spring Run**	Brook, Brown	4.5
Mifflinburg	Union	Buffalo Creek, N. Br.		13.3
	Union	**Rapid Run**	Brook*, Brown	10.9
Coburn	Mifflin	**Swift Run**	Brown*, Brook	2.2
	Centre	Pine Swamp Run		1.9
Tyrone	Blair	**Big Fill Run**	Brown, Brook	7.4
	Blair	**Vanscoyoc Run**	Brown, Brook	5.0
Woodward	Union	**Bear Run**	Brook	2.5
Southwest				
Mexico	Juniata	**Big Run**	Brook*, Brown	5.0
	Juniata	**Laurel Run**	Brook*, Brown	5.3
Newville	Cumberland	Back Creek		5.3
	Cumberland	Three Square Hollow Run		4.6
Chaneysville	Bedford	Blackberry Lick Run		2.1
	Bedford	Georgetown Branch		3.1
Blain	Perry	**Fowler Hollow Run**	Brook	6.2
	Perry	**Kansas Valley Run**	Brook*, Brown	4.0
McConnellsburg	Franklin	**Broad Run**	Brook	8.1
Mifflintown	Juniata	**Horning Run**	Brook, Brown	3.8
Hustontown	Fulton	Roaring Run		3.1
		Sipes Brook		3.4
Schellsburg	Bedford	Spicer Brook		4.4
Lewistown	Mifflin	**Granville Run**	Brook, Brown	3.4
Alexandria	Huntingdon	Emma Creek		2.2
Newton Hamilton	Mifflin	Wharton Run		2.9
Cassville	Huntingdon	**Laurel Run**	Brook	2.0
Breezewood	Fulton	Laurel Run		1.9
Landisburg	Perry	Green Valley Run	Brown	4.1

Table 4.4. USGS Quadrangles and Streams Randomly Selected From the Ridge and Valley Limestone Study Region
(Final quadrangles and streams selected after field reconnaissance are shown in bold.)

USGS Quad	County	Stream	Trout Species (*=Dominant)	Length (miles)	Upstream Limit	Downstream Limit
North						
Bellefonte	Centre	**Spring Creek**	Brown	18.8	Headwaters	Benner Twp. Line
Coburn	Centre	**Penns Creek**	Brown	12.0	Penns Cave	Elk Creek
	Centre	Pine Creek		1.5	SR 2018 Bridge Upstream Jct. T-507	Elk Creek
Howard	Centre	**Lick Run**	Brown	2.5	Headwaters	Mouth
Linden	Lycoming	**Antes Creek**	Brown*, Brook	3.4	Quarry near Oriole	Mouth
State College	Centre	**Cedar Run**	Brown	2.9	Headwaters	Mouth
Burnham	Mifflin	Tea Creek		1.1	US 322 Bridge	Mouth
	Mifflin	**Honey Creek**	Brown	3.8	Alexander Caverns	Mouth
Millheim	Clinton	Fishing Creek		12.3	Spring 427 m upstream T-350	Cherry Run
Bellefonte	Centre	Buffalo Run		12.2	Headwaters	Mouth
Beech Creek	Clinton	**Little Fishing Creek**		1.7	First bridge downstream Rt. 64 at Nittany	Mouth
South						
Carlisle	Cumberland	**Letort Spring Run**		8.7	Headwaters	Mouth
Newton Hamilton	Mifflin	**Long Hollow Run**	Brown	1.9	Second unnamed trib. From west upstream of mouth	Mouth
Roaring Spring	Blair	**Boiling Spring Run**	Brown*, Brook	3.4	Headwaters	Mouth
Wertzville	Cumberland	**Trindle Spring Run**	Rainbow*, Brown	0.9	Silver Springs	Mouth
New Enterprise	Bedford	**Potter Creek**	Brown, Brook	3.4	T-609	Mouth
Newville	Cumberland	**Big Spring Creek**	Brown, Brook	4.8	Headwaters	Mouth
Lemoyne	Cumberland	**Cedar Run**	Brown	3.3	Headwaters	Mouth
Chambersburg	Franklin	**Falling Spring Branch**	Brown, Rainbow	4.7	Falling Spring	Mouth
Clearville	Bedford	Ott Town Run		0.6	Headwaters	Mouth
Mercersburg	Franklin	Buck Run		2.0	Spring 100 m upstream Conrail crossing	Mouth

Table 4.4. ***USGS Quadrangles and Streams Randomly Selected From the Ridge and Valley Limestone Study Region—Continued***
(Final quadrangles and streams selected after field reconnaissance are shown in bold.)

USGS Quad	County	Stream	Trout Species (*=Dominant)	Length (miles)	Upstream Limit	Downstream Limit
East						
Hellertown	Northampton	**Monocacy Creek**	Brown*, Brook	14.7	Rt. 987 bridge at Bath	Mouth
Easton	Northampton	**Bushkill Creek**	Brown	7.1	LR 48021 bridge at Tatamy	Mouth
Allentown East	Lehigh	**Cedar Creek**	Brown	4.2	Headwaters	Mouth
	Lehigh	**Trout Creek**	Brown	1.6	Dixon St. bridge	Mouth
Hamburg	Berks	Moselem Creek		3.7	Headwaters	Mouth
Temple	Berks	Peters Creek		0.7	Headwaters	Mouth
Sinking Spring	Berks	**Spring Creek**	Brown, Brook	4.7	Headwaters	Mouth
Nazareth	Northampton	**Nancy Run**	Brown	2.8	Headwaters	Mouth

Table 4.5. USGS Quadrangles and Streams Randomly Selected From the Piedmont Upland Study Region
(Final quadrangles and streams selected after field reconnaissance are shown in bold.

USGS Quad	County	Stream	Trout Species	Length (miles)
Maryland Streams				
Conowingo Dam	Cecil	**Basin Run**	Brown	6.3
Woodbine	Carroll	**Gillis Falls**	Brown	8.4
Damascus	Howard/Montgomery	*Patuxent River	Brown	6.6
Finksburg	Baltimore	**Norris Run**	Brook	3.0
	Carroll	**Piney Run**	Brown	5.0
Phoenix	Baltimore	**First Mine Branch**	Brown, Brook	3.6
	Baltimore	**Greene Branch (Upper Section)**	Brook	2.0
	Baltimore	My Ladys Manor Branch	Brown, Brook	1.5
Norrisville	Harford	Jackson Branch	Brown	2.3
	Baltimore	**Third Mine Branch**	Brook	3.4
Reisterstown	Baltimore	**Cooks Branch**	Brook	2.0
	Baltimore	**Timber Run**	Brook	1.7
	Baltimore	*Red Run (Upper Section)	Brown, Brook	3.7
Towson	Baltimore	Fitzhugh Run	Brown	2.8
	Baltimore	Overshot Run	Brown	3.0
	Baltimore	*Dulaney Valley Branch (Upstream End)	Brown	1.6
Hereford	Baltimore	Buffalo Creek (Upper Half)	Brown, Brook	1.8
	Baltimore	Mingo Branch	Brook	1.3
	Baltimore	*Carroll Branch	Brown, Brook	4.7
New Freedom	Baltimore	Owl Branch	Brown, Brook	2.6
New Freedom	Baltimore	Fourth Mine Branch	Brook	3.0
	Baltimore	*Frog Hollow Branch	Brook	1.5
Jarrettsville	Harford	Overshot Branch	Brook, Brown	1.8
	Harford	South Stirrup Run	Brook	3.2
Cockeysville	Baltimore	*Dipping Pond Run	Brook, Brown	0.8
	Baltimore	***Baisman Run**	Brook, Brown	1.7
	Baltimore	*Deep Run (Upper Half)	Brown	1.1
Pennsylvania Streams				
Stewartstown	York	Rambo Run		8.0
Unionville	Chester	*Broad Run (Tributary to W. Branch Brandywine Creek)		6.0
Airville	York	Sawmill Run		2.5
	York	Furnace Run		3.2
Holtwood	Lancaster	Kellys Run		2.8
	Lancaster	Wissler Run		2.2
Parkesburg	Lancaster	Annan Run		2.0
	Lancaster	Knott Run		2.7
Unionville	Chester	Broad Run (Tributary to Valley Creek)		4.2
West Chester	Chester	Brinton Run		2.5
Conestoga	Lancaster	*Trout Run		3.5
Glen Rock	York	*Rehmeyer Hollow Run		1.2
Wagontown	Chester	*Lyons Run		2.2

*Alternate streams

Table 4.6 Summary of Potential Study Streams

Study Region	Number of Potential Study Streams				
	One Segment	Two Segments	Three Segments	Four Segments	Total
Ridge and Valley Limestone	22	2	4	1	29
Ridge and Valley Freestone	31	7	3	1	42
Unglaciated Plateau	47	15	2	0	64
Piedmont Upland	35	5	0	0	40

Field personnel selected streams so that the distribution of streams actually studied corresponded as closely as possible to the percentages of streams within each length category described above. Streams were randomly selected from the list by the field crews, and were either selected, or rejected, based on the following factors: access; landowner permission; presence or absence of man-made influences; presence of trout, as determined by electrofishing; and obvious water quality problems. Streams were selected first from the list of primary streams. Once all the primary streams had been visited, streams were selected from the list of alternates, as necessary.

Field reconnaissance showed some of the Pennsylvania streams selected did not have reproducing trout populations. Although these streams were selected from the PFBC data file of reproducing trout streams (section 4.2), many streams were included in that file, based on assumed similarity with other surveyed streams in the vicinity. Trout reproduction and trout species present in the Pennsylvania streams were verified either by searching PFBC files or by electrofishing by the field crews. The results of the verification are shown in Table 4.7. Trout reproduction was assumed to be occurring if fish less than 75 mm in length were found.

For the Maryland streams, trout reproduction and species present had been confirmed by Md. DNR (Steinfelt, 1991), and verification was not necessary. The trout species present in these streams also are shown in Table 4.7.

The streams selected after field reconnaissance are shown in bold type in Tables 4.2 through 4.5. Some of these streams were subsequently deleted because of problems experienced in the modeling phase of the study, as described in section 5.6. The final study sites are shown in Plate 1.

Table 4.7. Results of Trout Species Verification Studies

Stream	County	Pa. DEP* Subbasin	Trout Species Reproduction (Fish < 75 mm)	Data Source
Appalachian Plateau				
Northeast				
Tannery Hollow Run	Cameron	8A	Brook Trout	Electrofishing 6/22/94
Whitehead Run	Cameron	8A	Brook Trout**, Brown Trout	PFBC Files
Benner Run	Centre	8D	Brook Trout**, Brown Trout	PFBC Files
Meyers Run	Centre	9C	Brook Trout	Electrofishing 6/27/94
Mill Run	Clinton	9B	Brook Trout	Electrofishing 9/12/94
Strange Hollow	McKean	16C	Brook Trout	Electrofishing 6/22/94
Lyman Run	McKean	16C	Brook Trout	Electrofishing 6/21/94
Dunlap Run	Clearfield	8C	Brook Trout	Electrofishing 9/12/94
Bloomster Hollow	McKean	16C	Brook Trout	Electrofishing 6/21/94
Warner Brook	McKean	16C	Brook Trout	Electrofishing 6/20/94
Northwest				
East Branch Spring Creek	Elk	17A	Brook Trout, Brown Trout	PFBC Files
Cherry Run	Forest	16E	Brook Trout	Electrofishing 8/26/94
Seaton Run	Jefferson	17A	Brook Trout	Electrofishing 8/26/94
Lower Two Mile Run	Venango	16G	Brook Trout**, Brown Trout	PFBC Files
Sugar Camp Run	Jefferson	17C	No Trout	Electrofishing 9/12/94
Beech Run	Clearfield	17D	Brook Trout	PFBC Files
McEwen Run	Jefferson	17A	Brook Trout	Electrofishing 8/26/94
Rattlesnake Run	Jefferson	17A	Brook Trout	PFBC Files
South				
Coke Oven Hollow	Somerset	19E	Brook Trout	Electrofishing 9/16/94
Whites Creek	Somerset	19F	Brook Trout	PFBC Files
Red Run	Cambria	18D	Brook Trout	Surface Observations
Findley Run	Indiana	18D	Brook Trout**, Brown Trout	Surface Observations
Fall Creek	Somerset	19E	Brook Trout	PFBC Files
McClintock Run	Somerset	19F	Brook Trout	PFBC Files
Cush Creek	Indiana	8B	Brown Trout	PFBC Files

* Pennsylvania Department of Environmental Resources, 1971
** Dominant species

Table 4.7. Results of Trout Species Verification Studies—Continued

Stream	County	Pa. DEP* Subbasin	Trout Species Reproduction (Fish < 75 mm)	Data Source
Ridge and Valley Freestone				
Northeast				
Wapwallopen Creek	Luzerne	5B	Brown Trout**, Brook Trout	PFBC Files
Salem Creek	Luzerne	5D	Brook Trout**, Brown Trout	Electrofishing 9/7/94
Mugser Run	Columbia	5E	Brown Trout	PFBC Files
Green Creek	Columbia	5C	Brown Trout	PFBC Files
East Branch Raven Creek	Columbia	5C	Brook Trout	Electrofishing 9/25/95
Southwest				
Big Run	Juniata	12A	Brook Trout**, Brown Trout	PFBC Files
Laurel Run	Juniata	12A	Brook Trout**, Brown Trout	Electrofishing 9/15/94
Three Square Hollow Run	Cumberland	7B	No Trout	Electrofishing 10/7/94
Georgetown Branch	Bedford	13A	No Trout	Electrofishing 9/16/94
Kansas Valley Run	Perry	12B	Brook Trout**, Brown Trout	Electrofishing 9/15/94
Fowler Hollow Run	Perry	7A	Brook Trout	PFBC Files
Broad Run	Franklin	13C	Brook Trout	PFBC Files
Horning Run	Juniata	12A	Brook Trout, Brown Trout	PFBC Files
Granville Run	Mifflin	12A	Brook Trout, Brown Trout	Electrofishing 9/27/95
Laurel Run	Huntingdon	11D	Brook Trout	Electrofishing 10/11/95
Northwest				
Sand Spring Run	Union	10C	Brook Trout, Brown Trout	PFBC Files
Rapid Run	Union	10C	Brook Trout**, Brown Trout	PFBC Files
Swift Run	Mifflin	6A	Brook Trout, Brown Trout	Visual and PFBC Files
Big Fill Run	Blair	11A	Brown Trout, Brook Trout	PFBC Files
Bear Run	Union	6A	Brook Trout	PFBC Files
Vanscoyoc Run	Blair	11A	Brown Trout, Brook Trout	PFBC Files
Mile Run	Union	10C	Brook Trout	Electrofishing 10/13/94
Ridge and Valley Limestone				
North				
Spring Creek	Centre	9C	Brown Trout	PFBC Files
Penns Creek	Centre	6A	Brown Trout	PFBC Files
Lick Run	Centre	9C	Brown Trout	PFBC Files
Antes Creek	Lycoming	10A	Brown Trout**, Brook Trout	PFBC Files
Cedar Run	Centre	9C	Brown Trout	PFBC Files
Little Fishing Creek	Clinton	9C	Brown Trout, Brook Trout	PFBC Files***

* Pennsylvania Department of Environmental Resources, 1971 ** Dominant species

*** Natural reproduction has not been documented in this section, but it has been documented in the next section of the stream upstream of the study site

Table 4.7. Results of Trout Species Verification Studies—Continued

Stream	County	Pa. DEP* Subbasin	Trout Species Reproduction (Fish < 75 mm)	Data Source
Ridge and Valley Limestone—Continued				
South				
Boiling Spring Run	Blair	11D	Brown Trout**, Brook Trout	Electrofishing 9/23/94
Falling Spring Branch	Franklin	13C	Brown Trout, Rainbow Trout	PFBC Files
Potter Creek	Bedford	11D	Brown Trout, Brook Trout	PFBC Files
Big Spring Creek	Cumberland	7B	Brown Trout, Brook Trout	PFBC Files
Long Hollow Run	Mifflin	12C	Brown Trout	Electrofishing 9/15/94
Honey Creek	Mifflin	12A	Brown Trout	PFBC Files
Trindle Spring Run	Cumberland	7B	Rainbow Trout**, Brown Trout	PFBC Files
Letort Spring Run	Cumberland	7B	Brown Trout, Rainbow Trout	PFBC Files
Cedar Run	Cumberland	7E	Brown Trout	PFBC Files
East				
Monocacy Creek	Northampton	2C	Brown Trout**, Brook Trout	PFBC Files
Bushkill Creek	Northampton	1F	Brown Trout	PFBC Files
Cedar Creek	Lehigh	2C	Brown Trout	PFBC Files
Trout Creek	Lehigh	2C	Brown Trout	PFBC Files
Spring Creek	Berks	3D	Brown Trout, Brook Trout	PFBC Files
Nancy Run	Northampton	2C	Brown Trout	PFBC Files
Piedmont				
Maryland Streams				
Basin Run	Cecil		Brown Trout	MDNR Files
Gillis Falls	Carroll		Brown Trout	MDNR Files
Norris Run	Baltimore		Brook Trout	MDNR Files
Piney Run	Carroll		Brown Trout	MDNR Files
First Mine Branch	Baltimore		Brown Trout, Brook Trout	MDNR Files
Green Branch (Upper Section)	Baltimore		Brook Trout	MDNR Files
Third Mine Branch	Baltimore		Brook Trout	MDNR Files
Cooks Branch	Baltimore		Brook Trout	MDNR Files
Timber Run	Baltimore		Brook Trout	MDNR Files
Baisman Run	Baltimore		Brown Trout, Brook Trout	MDNR Files

* Pennsylvania Department of Environmental Resources, 1971
** Dominant species

5.0 DEVELOPMENT OF HABITAT VERSUS FLOW RELATIONSHIPS

5.1 Overview

Following the selection of the study sites, field data were collected for use in calibrating a hydraulic model. The calibrated hydraulic model was used to estimate the amount of habitat available under different flow conditions and also to develop wetted perimeter versus flow graphs. Hydrologic analyses were conducted to develop hydrology for the study sites, and to develop procedures for determining when to dispatch field crews.

In addition, the following studies were conducted:

- Spawning location characterization to verify criteria for transect placement, described in section 5.4; and
- Comparison of alternative types of suitability criteria, described in section 5.8.

There are many interactions among field data eolleetion, hydrologic analyses, and hydraulic model calibration, but each will be discussed separately in the following sections. The field site locations were used to select representative stream gages for hydrologic analyses, and flow measurements at some study sites were used to develop hydrology for those sites. The hydrology was used to help determine when to dispatch field crews to colleet additional data. For some streams, the additional data showed the initial gage selection or hydrologic computations were incorrect, and the field data were used to modify the hydrology. Similarly, the hydraulic modeling showed errors in some of the field data, requiring additional field data collection to resolve discrepancies.

The decision to estimate the habitat needs for a study region by analyzing the habitat needs for a number of sites within that region (section 2.0) helped establish the procedures for all aspects of the study, including data collection, hydraulic calibration and modeling, and available habitat analysis.

5.2 Study Site Selection

The segment boundaries were located in the field, and within those boundaries, a study site was selected. The study site was located at an accessible location closest to the midpoint of the segment, unless that location was not representative of the segment. If the location at the midpoint was considered not representative, an alternative study site was selected within the same segment. If the stream was determined to be unsuitable for use in the study (section 4.4), it was deleted from the list, and an alternate stream was selected.

When a study site was identified, the landowner was contacted for permission to enter the site. The landowner was given a letter explaining the project, and a brief explanation of what the crews would be doing, including the use of iron pins to mark the transect end points. If the landowner did not allow access, an alternate site in the same segment was sought, or an alternate stream was selected.

Information regarding the study segments that were selected upon completion of the field data collection stage of the study is summarized in Tables 5.1 through 5.4. These tables show additional detail regarding the streams shown in bold type in Tables 4.2 through 4.5. The number of streams and stream segments in each region at that stage are summarized in Table 5.5, which is comparable to Table 4.6. Four

Table 5.1. Data for Ridge and Valley Freestone Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Bear Run	Union	2.19	2.5	132	55	0	45	1
Big Fill Run, Seg. 1	Blair	7.98	3.7	314	0	57	43	2
Big Fill Run, Seg. 2	Blair	12.12	3.7	357	40	29	31	3
Big Run	Juniata	2.88	5.0	414	39	47	14	4
E. Br. Raven Creek	Columbia	2.48	2.9	535	28	25	47	90
Fowler Hollow, Seg. 1	Perry	1.81	3.1	795	56	24	20	6
Fowler Hollow, Seg. 2	Perry	5.52	3.1	328	34	32	34	7
Granville Run	Mifflin	2.74	3.4	788	50	34	16	91
Green Creek, Seg. 1	Columbia	2.55	4.0	788	49	33	18	9
Green Creek, Seg. 2	Columbia	9.42	4.0	825	32	32	36	10
Green Creek, Seg. 3	Columbia	33.24	4.0	1,010	17	17	66	11
Horning Run	Juniata	5.26	3.8	263	38	27	35	12
Kansas Valley Run	Perry	2.91	4.0	281	54	19	27	13
Laurel Run	Juniata	2.85	2.7	681	26	48	26	15
Laurel Run	Huntingdon	1.50	2.0	642	30	35	35	92
Mile Run	Union	1.37	1.2	254	22	47	31	16
Mugser Run, Seg. 1	Columbia	4.39	3.9	806	19	52	29	17
Mugser Run, Seg. 2	Columbia	8.92	3.9	655	68	33	0	18
Rapid Run, Seg. 1	Union	3.50	3.7	315	27	33	40	19
Rapid Run, Seg. 2	Union	10.74	3.7	340	35	31	34	20
Rapid Run, Seg. 3	Union	14.53	3.7	635	25	21	54	21
Salem Creek	Luzerne	2.70	4.5	839	56	31	13	22
Sand Spring Run	Union	3.22	4.5	401	26	53	21	23
Swift Run	Mifflin	3.03	2.2	99	59	41	0	24
Vanscoyoc Run	Blair	3.36	5.0	107	43	57	0	26
Wapwallopen Creek, Seg. 1	Luzerne	4.13	4.5	724	80	20	0	27
Wapwallopen Creek, Seg. 2	Luzerne	13.90	4.5	1,031	35	41	24	28
Wapwallopen Creek, Seg. 3	Luzerne	26.82	4.5	1,274	61	27	12	29
Wapwallopen Creek, Seg. 4	Luzerne	33.43	4.5	1,519	35	59	6	30

Table 5.2. Data for Ridge and Valley Limestone Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Antes Creek	Lycoming	52.00	3.4	982	41	32	27	31
Big Spring Creek	Cumberland	7.30	4.8	530	4	96	0	32
Boiling Spring Run	Blair	6.30	3.4	189	76	24	0	33
Bushkill Creek, Seg. 1	Northampton	59.37	3.5	468	28	72	0	34
Bushkill Creek, Seg. 2	Northampton	79.34	3.5	369	40	60	0	35
Cedar Creek	Lehigh	11.58	4.2	572	41	59	0	36
Cedar Run	Centre	13.94	2.9	1,001	18	66	16	37
Cedar Run	Cumberland	6.08	3.3	401	26	42	32	38
Falling Spring Run	Franklin	4.20	4.7	Not available	0	100	0	39
Honey Creek	Mifflin	91.45	3.8	723	20	41	38	41
Letort Creek, Seg. 1	Cumberland	3.79	4.3	1,000	0	100	0	41
Letort Creek, Seg. 2	Cumberland	17.00	4.3	1,300	0	100	0	42
Lick Creek	Centre	10.20	2.5	1,064	58	23	19	43
Little Fishing Creek	Centre	41.76	1.7	453	26	25	49	44
Long Hollow Run	Mifflin	6.34	1.9	535	23	22	55	45
Monocacy Creek, Seg. 1	Northampton	8.45	4.4	235	58	42	0	46
Monocacy Creek, Seg. 2	Northampton	34.79	4.4	Not available	0	100	0	47
Monocacy Creek, Seg. 3	Northampton	41.56	4.4	581	15	85	0	48
Nancy Run	Northampton	5.85	2.8	260	45	55	0	49
Penns Creek, Seg. 1	Centre	15.10	4.0	1,291	10	64	26	50
Penns Creek, Seg. 2	Centre	63.50	4.0	1,086	37	46	37	51
Penns Creek, Seg. 3	Centre	89.40	4.0	1,708	15	57	28	52
Potter Creek	Bedford	12.55	3.4	280	56	44	0	53
Spring Creek	Berks	19.68	4.7	937	18	34	48	54
Spring Creek, Seg. 1	Centre	29.70	4.7	1,150	28	35	37	55
Spring Creek, Seg. 2	Centre	58.55	4.7	1,093	8	31	61	56
Spring Creek, Seg. 3	Centre	79.10	4.7	1,414	27	64	9	57
Spring Creek, Seg. 4	Centre	86.30	4.7	1,395	54	42	4	58
Trindle Spring Run	Cumberland	19.55	0.9	1,392	49	51	0	59
Trout Creek	Lehigh	7.98	1.6	443	24	32	44	60

Table 5.3. Data for Unglaciated Plateau Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Beech Run	Clearfield	1.40	4.5	315	49	38	13	61
Benner Run	Centre	4.38	3.7	1,256	40	41	19	62
Bloomster Hollow	McKean	1.52	3.5	804	59	28	13	63
Cherry Run	Forest	3.35	3.2	243	29	40	31	64
Coke Oven Hollow	Somerset	1.22	3.0	226	72	0	28	65
Cush Creek, Seg. 1	Indiana	1.99	1.8	369	65	0	35	66
Cush Creek, Seg. 2	Indiana	4.85	6.1	495	42	58	0	67
Dunlap Run	Clearfield	1.20	2.7	932	24	16	60	68
E. Br. Spring Creek Seg. 2	Elk	11.45	5.7	562	30	37	33	70
Fall Creek, Seg. 1	Somerset	3.41	2.6	381	38	0	62	71
Fall Creek, Seg. 2	Somerset	5.89	2.6	315	83	0	17	72
Findley Run	Indiana	6.17	4.9	Not Available	100	0	0	73
Lower Two Mile Run, Seg. 1	Venango	2.72	3.5	356	42	22	36	74
Lower Two Mile Run, Seg. 2	Venango	8.43	3.5	509	42	29	29	75
Lyman Run	McKean	1.00	2.1	487	25	32	43	76
McClintock Run	Somerset	11.77	4.6	598	48	30	22	77
McEwen Run	Jefferson	2.13	3.1	257	33	46	21	78
Meyers Run	Centre	0.47	0.9	600	37	34	29	79
Mill Run	Clinton	1.70	1.7	945	53	16	31	80
Red Run	Cambria	1.43	2.5	259	62	20	18	82
Seaton Run	Jefferson	2.40	2.4	229	22	51	27	83
Strange Hollow	McKean	0.88	3.1	1,214	57	29	14	84
Tannery Hollow	Cameron	4.25	2.0	1,302	57	26	17	85
Warner Brook	McKean	3.22	3.7	1,109	51	36	13	86
Whites Creek, Seg. 1	Somerset	24.15	4.8	553	64	14	22	88
Whites Creek, Seg. 2	Somerset	31.79	4.8	Not available	0	100	0	89

Table 5.4. Data for Piedmont Upland Region Study Sites

Study Site Name	County	Drainage Area	Segment Length	Length Characterized	Mesohabitat			Stream Number (Plate 1)
					Riffle	Run	Pool	
		square miles	miles	feet	percent	percent	percent	
Baisman Run	Baltimore	1.33	1.7	729	42	40	18	93
Basin Run, Seg. 1	Cecil	2.08	3.2	687	26	14	60	94
Basin Run, Seg. 2	Cecil	9.77	3.2	956	41	30	29	95
Cooks Branch	Baltimore	0.87	2.0	847	20	58	22	96
First Mine Branch	Baltimore	5.07	3.6	1,030	49	32	19	97
Gillis Falls, Seg. 1	Carroll	2.26	4.2	533	42	25	33	98
Gillis Falls, Seg. 2	Carroll	7.79	4.2	1,430	39	37	24	99
Greene Branch	Baltimore	1.14	2.0	564	53	32	15	100
Norris Run	Carroll	2.04	3.0	669	42	27	31	101
Piney Run	Baltimore	5.09	5.0	865	20	31	49	102
Third Mine Branch	Baltimore	0.96	3.4	977	51	31	18	103
Timber Run	Baltimore	0.29	1.7	710	60	21	19	104

Table 5.5. Summary of Study Sites and Segments After Field Data Collection

Study Region	Number of Study Streams					Number of Segments
	One Segment	Two Segments	Three Segments	Four Segments	Total	
Ridge and Valley Limestone	16	2	2	1	21	30
Ridge and Valley Freestone	14	3	2	1	20	30
Unglaciated Plateau	19	5	—	—	24	29
Piedmont Upland	8	2	—	—	10	12
Grand Total					75	101

of these segments were deleted during the modeling phase, as described in section 5.6.2. The locations of the final study sites are shown in Plate 1.

5.3 Field Data Collection Procedures

Field procedures were designed to collect information necessary to develop a relationship between stage and discharge spanning the flow range of interest, and to model the aquatic habitat, for each study transect. The procedures included determining percentages of each mesohabitat type, locating transects, and collecting field data for model calibration. The necessary field data include: percentages of each mesohabitat type (riffle, run, pool); transect geometry; channel substrate/cover data; depth and water velocity at one flow; and water surface elevation for several flows.

Field data collection forms were developed specifically for this study, and sample forms are shown in Figures 5.1 through 5.4.

5.3.1 Mesohabitat percentages

The percentages of different mesohabitat types present were determined by defining a reach of stream at the site that contained either three repetitions of each of the mesohabitat types (riffle, run, or pool) present, or 1,000 feet of stream, whichever was greater. Then the lengths of each repetition of each mesohabitat type were measured and recorded on the Channel Type Data Sheet, (Figure 5.2), and the percentages of each mesohabitat type were computed and recorded.

5.3.2 Description of data sets

The calibrated hydraulic model is used to estimate depth and velocity over a range of simulation flows (section 5.7). Generally, the calibration process requires measurements at three flows that span the range of simulation flows. For the purpose of field data collection, the range of flows was assumed to range between the maximum and minimum median monthly flows.

In general, three satisfactory data sets were collected at each study site for hydraulic model calibration. For a number of limestone streams, the difference between the maximum median monthly flow and the minimum median monthly flow was small enough that only two satisfactory data sets were necessary to span that range, based on model extrapolation criteria discussed in section 5.3.3. A data set was considered satisfactory if the flow was in an appropriate range, if there were no irreconcilable errors in the data, and no inconsistencies among data sets. More than three site visits were necessary to collect the

INSTREAM FLOW FIELD

COMPLETE DATA

PAGE ____ OF ____

STREAM NAME ____ SEGMENT ____ OF ____

DATE ____ CREW MEMBERS & TASK ____

START TIME ____ FINISH TIME ____ COMPUTER DATA FILE ____

PHYSIOGRAPHIC REGION ____ GEOLOGY ____

TOPO MAP ____ COUNTY ____

BEST CHANNEL TYPE FOR DISCHARGE RIFFLE, RUN, POOL, ____ NO. OF X-SECT. THIS SEG. ____

DESCRIBE SITE LOCATION---

DID YOU COLLECT DATA ON THIS STREAM? ____ YES ____ NO

IF 'NO,' EXPLAIN IN DETAIL. (USE PAGE 2, IF NEEDED.)

DRAW SEGMENT STUDY LOCATION MAP. SHOW ROAD NAMES, LANDMARKS, & APPROXIMATE DISTANCE.

Figure 5.1. Sample Pennsylvania-Maryland Instream Flow Field Data Sheet for Complete Data Set

CHANNEL TYPE DATA SHEET

PAGE OF

ASSIGN A NAME TO EACH CHANNEL TYPE AND MEASURE DISTANCE FROM DOWNSTREAM HYDRAULIC CONTROL TO UPSTREAM FOOT OF SLOPED AREA IN WHOLE FEET

STREAM NAME ________ TOPO MAP ________

SEGMENT ____ OF ____

CHANNEL TYPE	LENGTH		CHANNEL TYPE	LENGTH			

NO. OF TROUT SPOTTED / SPECIES

SUMMARY

CHANNEL TYPE	NUMBER	TOTAL LENGTH	MEAN LENGTH	PERCENT			

Figure 5.2. Sample Pennsylvania-Maryland Instream Flow Channel Type Data Sheet

CROSS SECTION DATA SHEET (FLOW DATA, ELEV. DATA, PHYSICAL DATA)

PAGE ____ OF ____

STREAM NAME ____________________

SEGMENT ____ OF ____

CHANNEL TYPE: RUN, RIFFLE, POOL

TOPO MAP ____________________

BENCH MARK ELEV.=	100.00
BACKSIGHT READING +	
HEIGHT INSTRUMENT(LEVEL)=	

B.M. DESCRIPT. ____________________

DIST. TO CONTROL(PCCL) ________

DISCHARGE ________

STATION	PT. DESCRIP.	FORESIGHT	ELEV.	DEPTH	REV	TIME	VEL.	* SUBSTR	* COVER	
	I.P. LEFT									
	I.P. RIGHT									

LEVEL LOOP CLOSURE

BACKSIGHT +		B.S. DESCRIPTION--		
HI =				
FORESIGHT -		=	= BM	(100.0)

WATER SURFACE ELEV.=	LEFT	CENTER	RIGHT

* FOR SUBSTRATE AND COVER CODES SEE BACK OF PAGE #1

SEE BACK FOR X-SECTION SKETCH

Figure 5.3. Sample Pennsylvania-Maryland Instream Flow Cross-Section Data Sheet

INSTREAM FLOW FIELD DATA

PARTIAL DATA SET

PAGE ____ OF ____

STREAM NAME ____________________ SEGMENT ____ OF ____

DATE ____________ CREW MEMBERS & TASK ____________

PHYSIOGRAPHIC REGION ____________ GEOLOGY ____________

TOPO MAP ____________ COUNTY ____________

CHANNEL TYPE ____________

		FORESIGHT	ELEV.
BENCH MARK ELEV. =			
BACKSIGHT READING +			
HI =			
LEFT EDGE WATER			
RIGHT EDGE WATER			
I.P. LEFT			
I.P. RIGHT			
LEVEL LOOP CLOSURE			
BACKSIGHT +			
HI =			
FORESIGHT -			
BM. =			

CHANNEL TYPE ____________

		FORESIGHT	ELEV.
BENCH MARK ELEV. =			
BACKSIGHT READING +			
HI =			
LEFT EDGE WATER			
RIGHT EDGE WATER			
I.P. LEFT			
I.P. RIGHT			
LEVEL LOOP CLOSURE			
BACKSIGHT +			
HI =			
FORSIGHT -			
BM. =			

Figure 5.4. Sample Pennsylvania-Maryland Instream Flow Field Data Sheet for Partial Data Set

required number of satisfactory data sets for some streams because measured flows were too close together, or due to measurement errors or inconsistencies.

The three data sets generally included a complete data set (CDS) and two partial data sets (PDS). Ideally, the CDS should be collected at a higher flow than the PDS. Where the CDS flow was greater than, or equal to, the target for the highest flow (section 5.3.3), two low flow partial data sets were collected.

However, in many cases, the CDS was collected at a flow less than necessary to simulate the highest median monthly flow, based on the extrapolation criteria described in section 5.3.3, and in some cases the CDS was within the flow range necessary to simulate the lowest median monthly flow. In those cases, it was necessary to collect one or two additional data sets at flows greater than the complete data set flow. The hydraulic model calibration procedure recommends depth and velocity measurements be made at the highest flow, because the flow submerges the greatest channel width. Therefore, depth and velocity measurements had to be collected as part of any high flow PDS.

The CDS included the following measurements: depths and velocities at each measurement point for each transect; bottom and overbank survey for each transect; water surface elevations; and substrate and cover codes at each measurement point for each transect. Depth and velocity measurements at one of the transects were used to compute the flow rate. Also, the stream reach was photographed.

For high flow PDSs, depth, velocity, and water surface elevation measurements were required at each transect. Again, the depth and velocity measurements at one transect were used to compute flow rate. Depths and velocities were measured at all transects at the same points used for the CDS. Additional points were measured if the increased flow covered cells that were dry during the complete data set measurement. Substrate and cover were not required for this data set.

For low flow PDSs, only water surface elevations at all transects and a flow rate measurement were required. The hydraulic model calibration procedure does not require depth and velocity measurements for this data set. The discharge measurement was normally made at one of the original transects, but changing flow conditions occasionally required the measurement be made at a nearby location.

In some instances, several complete data sets were gathered at a given study site, as a result of:

- Changes in channel bottom configuration;
- Changes caused by construction of a beaver dam, or seasonal variations in aquatic vegetation; or
- Incorrect location of the original study site.

5.3.3 Model calibration and flow range criteria

Usually, field data cannot be collected over the entire range of discharges that need to be simulated, so the calibrated model must extrapolate to flows outside the calibration range. Also, the measured flow rates used in the hydraulic calibration process need to be sufficiently different to obtain a valid hydraulic calibration. As noted in section 5.3.2, for the purpose of data collection, the simulation flows were assumed to range between maximum median monthly flow and minimum median monthly flow.

The hydraulic model can reasonably be extrapolated to a flow equal to 1.5 times the highest calibration flow and 0.6 times the lowest calibration flow. The absolute maximum range for extrapolation is to a flow 2.5 times the highest calibration flow and 0.4 times the lowest calibration flow (U.S. Geological Survey, Biological Resources Division, 1994).

These extrapolation limits are summarized in Table 5.6, along with the target range of measured flows derived from the normal extrapolation limits. To satisfy the normal extrapolation limits shown in the table, the highest measurement flow should equal, or exceed, the target value (column 4) multiplied by the maximum median monthly flow, and the lowest flow measurement should be less than the target value multiplied by the minimum median monthly flow. It was assumed that valid calibration could be obtained if the lower flow is less than 50 percent of the higher flow. These criteria were used to determine the range of flows for field data collection.

Table 5.6. Hydraulic Simulation Limits and Flow Targets

Measurement Flow	Normal Extrapolation Limit	Maximum Extrapolation Limit	Measurement Flow Target*
Highest	1.5 times	2.5 times	0.67
Lowest	0.6 times	0.4 times	1.67

* Based on normal extrapolation limit.

For any study stream, the range between maximum and minimum median monthly flows can be subdivided, based on the extrapolation limits, and the criterion that flows used for calibration should differ by at least 50 percent. The relationship of the complete and partial data set flows to each other, and the criteria for determining targets, are shown in Table 5.7. In this table, Threshold 1 is the highest acceptable value of the lowest measurement flow, and the lowest acceptable value of the intermediate measurement flow. Threshold 2 represents the highest acceptable value of the intermediate measurement flow and the lowest acceptable value of the highest measurement flow.

Table 5.7. Flow Relationships and Target Measurement Flows

Threshold 1		Threshold 2
Lowest Measurement Flow	Intermediate Flow	Highest Measurement Flow
PDS-1 <= MIN(0.5*PDS-2, 1.67*Minimum MM Flow)	PDS-2 <= 0.5*CDS AND >=2.0*PDS-1	CDS
PDS-1 <=MIN(0.5*CDS, 1.67*Minimum MM Flow	CDS	PDS-2 >= MAX(2.0*CDS, 0.67*Maximum MM Flow)
CDS	PDS-1 >= 2.0*CDS AND <=0.5*PDS-2	PDS-2 >= MAX(2.0*PDS-1, 0.67*Maximum MM Flow)

Key

CDS = Compete data set flow measured
PDS-1 = target flow for lower partial data set
PDS-2 = target flow for higher partial data set
MM= median monthly
MAX = maximum value
MIN = minimum value

5.3.4 Field measurement procedures

For each of the mesohabitat types observed, a representative occurrence of that type was selected, and a transect was established near the midpoint. The transect was located perpendicular to the streamflow.

The placement of transects at the midpoint of the selected mesohabitats resulted in questions regarding whether that location adequately represented habitat for the spawning life stage. A study of spawning locations, described in section 5.4, showed spawning habitat was adequately sampled.

Field data were collected in accordance with procedures described by Bovee (undated). Temporary benchmark(s) was (were) set at each study site and assigned an arbitrary elevation. Transects were marked at both ends with reinforcing bar, and referenced to nearby topographic features.

Velocity and discharge measurements and discharge computations followed the procedures described by Buchanan and Somers (1969). Velocity measurements were made with either rotating cup meters (Price Type AA current meter or pygmy meter), or a Marsh-McBirney electromagnetic meter. Although no direct comparisons of velocity measurements between different meters were made as part of this study, general experience of the study participants is that velocity measurements made with the electromagnetic meter compare very well with measurements made with either of the rotating cup meters. Where substantial vegetation was present, the electromagnetic meter was used, because the cup rotation was restricted. The electromagnetic meter did not work well where velocities were very low.

For most transects, depth and velocity measurements were made at 15 to 25 points across the transect. Measurements were made at points where either bottom contour, velocity, substrate, or cover changed. Generally, flow measurement points were selected so that each partial section of the transect between measurement points included no more than 10 percent of the total flow. The exact number of measurements depended upon flow conditions. Bottom elevations were surveyed at each measurement point during collection of the complete data set.

Water surface elevations were measured at each transect at the left and right edges of water, as a minimum. One or more midstream elevations were measured if the water surface elevation varied across the transect.

Substrate and cover codes were determined at each measurement point, using the coding scheme described in section 3.1.2. These codes were generally determined only once, and assumed constant throughout the study.

In many instances when a revised CDS was collected, the original CDS was utilized as a partial data set during model calibration.

5.3.5 Problems encountered

The problems encountered during the study site selection and field data collection phases of the study are described in Appendix C. Aquatic vegetation frequently caused difficulty in obtaining valid velocity and flow measurements. Seasonal changes in vegetation resulted in changes in depth, velocity and roughness for different measurements, which made hydraulic calibration difficult, and in some cases impossible. For some streams, changes in transect geometry between measurements, usually as a result of high flows, also caused inconsistencies between measurements and required collection of

additional data, or in some cases, deletion of a study site. Some study streams in the Piedmont Upland in Maryland showed signs of unstable bed and banks, as discussed in Appendix C. Future hydraulic and habitat conditions for these streams may be different from current conditions, so the habitat analyses should be used with caution. Also, withdrawals from these streams may affect sediment transport and channel morphology, which should be considered further in impact analyses.

5.3.6 Data processing procedures

The field data was logged into a data tracking form as it was received. The form was used to track data processing status.

Field data for the CDSs were checked for completeness. All field calculations were checked, and all other calculations, including the flow rate, were completed and checked. The location of the site was plotted on a USGS quadrangle map using information provided in the field notes. The watershed boundary was delineated, and the drainage area was planimetered and checked. Then all the data were entered into the PHABSIM computer model, as described in section 5.6.1.

PDS field notes were processed in the same way as CDS notes. In addition, benchmark descriptions and end pin elevations were compared with previous data sets to check for discrepancies. Water surface elevations and flow rates were tabulated and checked to ensure that changes in elevations were consistent with changes in discharge.

5.4 Spawning Location Characterization Procedure and Results

The procedures for locating transects for physical habitat measurements (section 5.3.4) placed each transect in the center of each mesohabitat type (i.e., riffles, runs, and pools). This placement of transects could result in missing much of the spawning habitat if the fish do not spawn in the center of the mesohabitat type. PFBC biologists suggested trout redds (nests) are often found in the downstream or tail end of pools. Transects placed in the middle of this mesohabitat type would miss these spawning areas. To determine whether the placement of transects would affect the evaluation of spawning habitat, a study was conducted during the fall spawning period to document the location of redds in each mesohabitat type.

5.4.1 Methods for studying spawning location

The following criteria were used to identify redds:

- Observation of spawning trout occupying redds;
- Identification of areas that had been swept clean of algae and silt, as observed during an October 11, 1994, field trip to Little Fishing Creek in Centre County; and
- Probing the suspected redds with a walking stick to determine if the sediments were loose.

Dr. Robert Carline of the Pennsylvania State University instructed field personnel on how to identify trout redds during the October 11, 1994, field trip to Little Fishing Creek.

The list of all study streams, including the trout species (brook trout or brown trout) inhabiting each stream, was furnished to the field crews. An attempt was made to sample brook trout streams during October, which is the peak spawning period for that species. When possible, brown trout streams were sampled in November, the peak spawning period for that species.

The field crews walked about 300 m. (1,000 ft) of each stream, which corresponded as closely as possible with the area of the stream that was used to determine the percentage of each mesohabitat type (section 5.3.1). Each mesohabitat type was divided into four parts, as shown schematically on the Spawning Data Sheet shown in Figure 5.5. The location of each redd relative to each mesohabitat type was recorded on the diagram. The depth, average column velocity, and substrate type for each redd also were recorded.

5.4.2 Results of spawning location study

A summary of the streams sampled, and the number of redds observed, is shown in Table 5.8. Thirty streams and 31 stream segments were evaluated. Nineteen streams and 20 segments were identified as either exclusively or dominantly inhabited by brook trout. Seven streams and seven stream segments were identified as exclusively or dominantly populated by brown trout. The remaining four streams and four stream segments were inhabited by both brook and brown trout, with neither species clearly dominant. Where brook trout were dominant, redds were assumed to be primarily created by brook trout; where brown trout were dominant, the redds were assumed to be created by brown trout; where neither species was dominant, the species was considered unidentified. One hundred twenty-three redds were located on brook trout streams, 29 redds on the brown trout streams, and 24 redds on the streams where neither species was dominant.

In spite of the field training, crews had difficulty identifying redds. Many of the redds were recorded as "potential" redds because, although they generally met the criteria, the crews did not consider the identification to be definitive. Sixty-five percent of the brook trout redds were listed as "potential", as were 69 percent of the brown trout redds and 92 percent of the unidentified redds. The following discussion is based on the assumption that all "potential" redds were actual redds.

The locations of the redds in each mesohabitat type for brook trout, brown trout, unidentified species, and for all streams combined, respectively, are shown in Tables 5.9 through 5.12. Most brook trout redds were located either in pools (54.5 percent) or runs (41.5 percent), while the remaining 4.1 percent were located in riffles (Table 5.9). In pools, the proportion of redds increased from the head-end to the tail-end, as expected. However, since the middle half of the pools had a significant percentage of redds, sampling in this portion of the pool should ensure some redd locations were included in the sample. For riffles and runs, the greatest proportions of the redds were located near the center of the mesohabitat types.

Twenty-four of the 29 (82.8 percent) brown trout redds were located in runs, and most of these redds were located in the center of that mesohabitat type (Table 5.10). Only five brown trout redds were located in riffles or pools, so little can be said about their relative location in these mesohabitats.

Twenty-one of the 24 unidentified trout redds also were located in runs (Table 5.11). All were located in the central 50 percent of this habitat type.

The depth, velocity, and substrate measurements for the various redd locations are shown in Table 5.13, and summarized in Table 5.14. Brook trout redds were located at depths ranging from 0.2 to 2.0 ft, with a mean depth of 0.7 ft. Velocities ranged from 0 to 1.03 ft/sec, and the mean velocity was 0.24 feet per second (ft/sec). The primary substrate type in most brook trout redds was gravel (0.12-2.15 inches in diameter). One redd was found in an area of primarily sand (< 0.12 inches in diameter); three were found in substrate predominantly larger than gravel. However, the field notes

PENNSYLVANIA INSTREAM FLOW STUDY
SPAWNING DATA SHEET

STREAM NAME______________________ SEGMENT______OF______ TOPO MAP____________________

FLOW DIRECTION

------------------------------->

POOL	**RIFFLE**	**RUN**

INSTRUCTIONS: DOCUMENT LOCATION OF REDD RELATIVE TO EACH MESOHABITAT TYPE ABOVE USING CONSECUTIVE ORDER NUMBER. THEN RECORD DEPTH AND SUBSTRATE CODE AT EACH REDD CORRESPONDING WITH ITS ASSOCIATED NUMBER. REPORT ANY COMMENTS ON BACK OF THIS DATA SHEET.

REDD #	DEPTH	SUBSTR.#		REDD #	DEPTH	SUBSTR.#		REDD #	DEPTH	SUBSTR.#	
1				13				25			
2				14				26			
3				15				27			
4				16				28			
5				17				29			
6				18				30			
7				19				31			
8				20				32			
9				21				33			
10				22				34			
11				23				35			
12				24				36			

Figure 5.5. Sample Spawning Data Sheet

Table 5.8. Streams Evaluated for Redd Locations, October–November 1994

Stream	Study Region	County	Subbasin	Seg. No.	Species (* = Dominant)	Date	No. of Redds
Brook Trout or Brook Trout-Dominant Streams							
Cherry Run	Unglaciated Plateau	Forest	16E	1	Brook Trout	10/21/94	2
McEwen Run	Unglaciated Plateau	Jefferson	17A	1	Brook Trout	10/20/94	3
Lyman Run	Unglaciated Plateau	McKean	16C	1	Brook Trout	10/18/94	2
Strange Hollow	Unglaciated Plateau	McKean	16C	1	Brook Trout	10/18/94	5
Tannery Hollow Run	Unglaciated Plateau	Cameron	8A	1	Brook Trout	10/19/94	3
Meyers Run	Unglaciated Plateau	Centre	9C	1	Brook Trout	10/19/94	1
Dunlap Run	Unglaciated Plateau	Clearfield	8C	1	Brook Trout	10/19/94	1
Mill Run	Unglaciated Plateau	Clinton	9B	1	Brook Trout	10/18/94	8
Coke Oven Hollow	Unglaciated Plateau	Somerset	19E	1	Brook Trout	10/14/94	7
Broad Run	Ridge and Valley Freestone	Franklin	13C	1	Brook Trout	11/17/94	14
Fowler Hollow Run	Ridge and Valley Freestone	Perry	7A	1	Brook Trout	11/03/94	6
Fowler Hollow Run	Ridge and Valley Freestone	Perry	7A	2	Brook Trout	11/18/94	20
Bear Run	Ridge and Valley Freestone	Union	6A	1	Brook Trout	10/12/94	9
Mile Run	Ridge and Valley Freestone	Union	10C	1	Brook Trout	10/13/94	9
Lower Two Mile Run	Unglaciated Plateau	Venango	16G	1	Brook Trout*, Brown Trout	11/15/94	5
Whitehead Run	Unglaciated Plateau	Cameron	8A	1	Brook Trout*, Brown Trout	10/18/94	6
Benner Run	Unglaciated Plateau	Centre	8D	1	Brook Trout*, Brown Trout	10/19/94	2
Kansas Valley Run	Ridge and Valley Freestone	Perry	12B	1	Brook Trout*, Brown Trout	11/18/94	14
Salem Creek	Ridge and Valley Freestone	Luzerne	5D	1	Brook Trout*, Brown Trout	10/20/94	3
Rapid Run	Ridge and Valley Freestone	Union	10C	1	Brook Trout*, Brown Trout	11/09/94	3
Subtotal							123

Table 5.8. Streams Evaluated for Redd Locations, October–November 1994—Continued

Stream	Study Region	County	Subbasin	Seg. No.	Species (* = Dominant)	Date	No. of Redds
Brown Trout or Brown Trout-Dominant Streams							
Cush Creek	Unglaciated Plateau	Indiana	8B	2	Brown Trout	11/04/94	1
Honey Creek	Ridge and Valley Limestone	Mifflin	12A	1	Brown Trout	11/04/94	6
Long Hollow Run	Ridge and Valley Limestone	Mifflin	12C	1	Brown Trout	11/04/94	3
Spring Creek	Ridge and Valley Limestone	Centre	9C	3	Brown Trout	10/20/94	2
Cedar Run	Ridge and Valley Limestone	Centre	9C	1	Brown Trout	11/10/94	4
Falling Spring Branch	Ridge and Valley Limestone	Franklin	13C	1	Brown Trout, Rainbow Trout	11/02/94	11
Wapwallopen Creek	Ridge and Valley Freestone	Luzerne	5B	4	Brown Trout*, Brook Trout	10/21/94	2
Subtotal							**29**
Streams With Neither Species Dominant							
Horning Run	Ridge and Valley Freestone	Juniata	12A	1	Brook Trout, Brown Trout	10/26/94	1
Little Fishing Creek	Ridge and Valley Limestone	Clinton	9C	1	Brown Trout, Brook Trout	11/04/94	3
Potter Creek	Ridge and Valley Limestone	Bedford	11D	1	Brown Trout, Brook Trout	11/01/94	11
Big Spring Creek	Ridge and Valley Limestone	Cumberland	7B	1	Brown Trout, Brook Trout	11/02/94	9
Subtotal							**24**
Grand Total							**176**

Table-5.9. Location of 123 Brook Trout Redds in 19 Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study
(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories.)

FLOW DIRECTION

→

Right Bank		2	4			1	1		2	4	2	
	3	5	6	8					4	5	4	1
	5	4	6	8		1	1		5	3	3	5
Left Bank		1	3	1		1				8	4	1
Total %	6.5	9.8	15.4	22.8		2.4	1.6		8.9	16.3	10.6	5.7
	POOL 67 Redds (54.5%)				RIFFLE 5 Redds (4.1%)				RUN 51 Redds (41.5%)			

Table 5.10. ***Location of 29 Brown Trout Redds in Seven Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study*** *(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories.)*

FLOW DIRECTION

→

Right Bank										4	2	
			1	1							3	1
	2					1				2	4	1
Left Bank										6		1
Total %	6.9		3.4	3.4		3.4				41.3	31.0	10.3

POOL
4 Redds
(13.9%)

RIFFLE
1 Redd
(3.4%)

RUN
24 Redds
(82.8%)

Table-5.11. *Location of 24 Unidentified Trout Redds in Four Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study* *(The number of redds in each location is given in a schematic plan view of the stream along with the percentages of redds in the various categories.)*

FLOW DIRECTION

→

Right Bank							1			1	2	
			1			1				4	1	
										3		
Left Bank										7	3	
Total %			4.2			4.2	4.2			62.5	25.0	
	POOL 1 Redd (4.2%)				RIFFLE 2 Redds (8.3%)				RUN 21 Redds (87.5%)			

Table 5.12. ***Location of 176 Trout Redds (Brook Trout, Brown Trout, and Unidentified Trout Combined) in 30 Streams Evaluated as Part of the Pennsylvania-Maryland Instream Flow Study***
(The number of redds in each location is given in a schematic plan view of a stream along with the percentages of redds in the various categories)

FLOW DIRECTION
→

Right Bank		3	4	10		1	2		2	9	6	
	3	5	8	9		1			4	9	8	2
	7	3	6	9		2	1		5	7	7	6
Left Bank		1	3	1			1			21	7	2
Total %	5.7	6.9	12.0	16.6		2.3	2.3		6.3	26.3	16	5.7

POOL	RIFFLE	RUN
72 Redd	8 Redds	96 Redds
(41.1%)	(4.6%)	(54.3%)

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds				
Cherry Run	1	0.40	0.419	Gravel
	2	0.30	1.029	Gravel
McEwen Run	3	0.55	0.050	Gravel
	4	0.35	0.121	Gravel
	5	0.25	0.432	Gravel
Lyman Run	6	0.35		Gravel
	7	0.40		Gravel
Strange Hollow	8	0.60		Gravel
	9	0.40		Gravel
	10	0.30		Gravel
	11	0.50		Gravel
	12	0.50		Gravel
Tannery Hollow	13	0.22		Gravel
	14	0.55		Gravel
	15	0.64		Gravel
Meyers Run	16	0.56		Gravel
Dunlap Run	17	0.50		Gravel
Mill Run	18	0.60		Gravel
	19	0.80		Gravel
	20	0.16		Gravel
	21	0.55		Gravel
	22	0.65		Gravel
	23	1.15		Gravel
	24	0.60		Gravel
	25	0.55		Gravel
Coke Oven Hollow	26	0.60	0	Gravel
	27	0.75	0	Gravel
	28	0.90	0	Gravel
	29	1.30	0	Gravel
	30	0.40	0	Gravel
	31	0.50	0	Gravel
	32	0.15	0	Gravel
Broad Run	33	0.60	0.565	Gravel
	34	0.60	0.100	Gravel
	35	0.55	0.218	Gravel
	36	0.85	0.383	Gravel
	37	1.05	0.188	Gravel
	38	1.00	0.334	Gravel
	39	0.60	0.256	Gravel
	40	0.80	0.217	Gravel
	41	0.50	0.050	Gravel
	42	0.60	0.177	Gravel
	43	0.70	0.425	Gravel
	44	0.85	0.262	Gravel
	45	0.70	0.169	Gravel
	46	0.80	0.266	Gravel

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds—Continued				
Fowler Hollow Run Segment 1	47	0.45	0.514	Gravel
	48	0.80	0.356	Gravel
	49	0.55	0.050	Gravel
	50	0.50	0.106	Gravel
	51	0.90	0.291	Gravel
	52	0.85	0.378	Sand
Fowler Hollow Run Segment 2	53	1.10	0.530	Gravel
	54	0.90	0.133	Gravel
	55	0.30	0.267	Gravel
	56	0.90	0.469	Gravel
	57	0.40	0.267	Gravel
	58	0.40	0.953	Gravel
	59	0.40	0.176	Gravel
	60	0.60	0.381	Gravel
	61	0.60	0.168	Gravel
	62	0.70	0.050	Gravel
	63	0.90	0.355	Gravel
	64	0.70	0.050	Gravel
	65	1.10	0.325	Rock
	66	1.20	0.050	Gravel
	67	0.50	0.050	Gravel
	68	0.50	0.206	Gravel
	69	0.60	0.050	Rock
	70	1.50	0.282	Gravel
	71	1.30	0.453	Rock
	72	0.70	0.076	Gravel
Bear Run	73	0.85	0.340	Gravel
	74	0.40	0.000	Gravel
	75	0.20	0.299	Gravel
	76	1.60	0.255	Gravel
	77	1.20	0	Gravel
	78	1.80	0.042	Gravel
	79	1.90	0.042	Gravel
	80	2.00	0.042	Gravel
	81	2.00	0.042	Gravel
Mile Run	82	0.35	0.419	Gravel
	83	0.40	0.321	Gravel
	84	0.30	0.101	Gravel
	85	0.40	0.462	Gravel
	86	0.40	0.144	Gravel
	87	0.40	0.150	Gravel
	88	0.45	0.240	Gravel
	89	0.40	0.255	Gravel
	90	0.50	0.118	Gravel

Table-5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brook Trout Redds—Continued				
Lower Two Mile Run	91	1.10	0.401	Sand
	92	0.85	0.050	Gravel
	93	1.40	0.153	Gravel
	94	0.40	0.625	Gravel
	95	1.10	0.164	Gravel
Whitehead Run	96	0.18		Gravel
	97	0.41		Gravel
	98	0.37		Gravel
	99	0.64		Gravel
	100	0.77		Gravel
	101	0.98		Gravel
Benner Run	102	0.76		Gravel
	103	0.33		Gravel
Kansas Valley Run	104	0.75	0.077	Gravel
	105	0.70	0.314	Gravel
	106	0.55	0.659	Gravel
	107	0.40	0.320	Gravel
	108	0.50	0.308	Gravel
	109	0.40	0.304	Gravel
	110	0.45	0.202	Gravel
	111	0.50	0.050	Gravel
	112	0.60	0.050	Gravel
	113	0.45	0.050	Rock
	114	0.30	0.050	Gravel
	115	0.50	0.268	Gravel
	116	0.40	0.401	Gravel
	117	0.60	0.296	Gravel
Salem Creek	118	0.36		Gravel
	119	0.30		Gravel
	120	0.30		Gravel
Rapid Run	121	0.62	0.761	Gravel
	122	0.70	0.435	Gravel
	123	0.45	0.516	Gravel
Brown Trout Redds				
Cush Creek	1	0.62	0.860	Gravel
Honey Creek	2	0.60	0.061	Gravel
	3	0.40	0	Gravel
	4	1.10	0.524	Sand
	5	0.70	0.168	Gravel
	6	0.75	0.509	Gravel
	7	0.75	1.080	Gravel
Long Hollow Run	8	0.80	0.445	Gravel
	9	0.50	0.397	Gravel
	10	0.80	0.253	Gravel
Spring Creek	11	1.20		Gravel
	12	1.20		Gravel

Table 5.13. Depths, Velocities, and Substrate Types for Trout Redds—Continued

Stream Name	Redd Number	Depth (ft)	Velocity (ft/sec)	Substrate
Brown Trout Redds—Continued				
Cedar Run	13	0.50	0.332	Gravel
	14	0.90	0.117	Gravel
	15	1.05	0.338	Gravel
	16	1.35	0.167	Gravel
Falling Spring Branch	17	0.90	1.636	Gravel
	18	1.30	0.929	Gravel
	19	0.60	0.473	Gravel
Falling Spring Branch	20	0.65	0.285	Gravel
	21	1.25	1.947	Gravel
	22	0.70	1.120	Gravel
	23	1.30	0.690	Gravel
	24	1.20	0.486	Gravel
	25	1.40	1.073	Gravel
	26	1.10	0.602	Gravel
	27	1.60	0.432	Gravel
Wapwallopen Creek	28	1.35	1.660	Gravel
	29	1.10	1.690	Gravel
Both Species				
Horning Run	1	1.35	0.165	Gravel
Little Fishing Creek	2	1.10	0.114	Gravel
	3	1.50	0.343	Gravel
	4	0.50	0.404	Gravel
Potter Creek	5	0.45	0.560	Gravel
	6	0.50	0.874	Gravel
	7	0.70	0.705	Sand
	8	0.80	1.140	Sand
	9	0.70	1.270	Gravel
	10	0.45	0.753	Gravel
	11	0.55	0	Sand
	12	0.95	0.712	Sand
	13	0.90	0.384	Sand
	14	0.75	0.727	Gravel
	15	0.80	1.464	Gravel
Big Spring Creek	16	1.30	0.997	Gravel
	17	1.55	0.614	Gravel
	18	1.55	0.540	Gravel
	19	1.30	1.324	Gravel
	20	1.40	0.650	Gravel
	21	1.85	1.012	Gravel
	22	1.60	0.818	Gravel
	23	1.90	1.053	Gravel
	24	1.90	1.026	Gravel

Table 5.14. Summary of Depths, Velocities, and Substrate Types at Redd Locations for Brown Trout and Brook Trout

	Depth (ft)				Velocity (ft/sec)				Substrate Type (%)			
	# Redds	Mean	Maximum	Minimum	# Redds	Mean	Maximum	Minimum	# Redds	Sand/Silt	Gravel	Rock
Brook Trout	123	0.7	2.0	0.15	90	0.24	1.03	0	129	0.8	88.4	10.7
Brown Trout	29	1.0	1.6	0.40	27	0.68	1.96	0	29	3.4	96.6	0
Unidentified Trout	24	1.1	1.9	0.45	24	0.74	1.46	0	24	21.0	79.2	0
Total	176	0.8	2.0	0.15	141	0.41	1.95	0	176	4.0	88.5	7.4

indicated gravel was probably present in these areas, between the larger substrate, so the actual redds may have been in the gravel.

Brown trout redds were located at depths ranging from 0.4 to 1.6 ft, with a mean of 1.0 ft. Velocities ranged from 0 to 1.9 ft/sec, with a mean of 0.68 ft/sec. Gravel substrate was dominant for all except one of the redds, which was located in sand.

Unidentified trout redds were found in depths ranging from 0.5 to 1.9 ft, with a mean of 1.1 ft. Velocities ranged from 0 to 1.46 ft/sec, with a mean of 0.74 ft/sec. These redds were primarily found in gravel (79.2 percent), with the remaining 20.8 percent of redds found in sand.

5.4.3 Conclusion

The reason for studying spawning location was to document the relative position of redds in the various mesohabitats sampled. The primary concern was whether sampling in the midpoint of the riffles, runs, or pools would adequately represent the areas used for spawning.

Analysis and interpretation of the data are problematic because of the uncertainty regarding redd identification. Future studies of redd location should include procedures for verification of redd identification such as that used in the transferability study (section 3.4.2). The following conclusions are based on the assumption that all redds listed as "potential" on the field data forms were actual redds.

Although the number of brook trout redds in the pools increased in a downstream direction, the proportion of redds in the middle half of the pools (25.2 percent) was about the same as in the downstream quarter of the pool (22.8 percent). Therefore, transects placed in the center of the pools should be representative of trout spawning habitat. In future studies, it would be desirable to also include a transect in the tail of the pools in order to include the area that has the highest proportion of redds.

In runs, which had 41.5 percent of the brook trout redds (compared to 54.5 percent in the pools), and the majority of both the brown trout (82.8 percent) and unidentified trout redds (83.3 percent), the center of the mesohabitat was the most likely place to find redds. This also was true for riffles, although there were very few redds found in riffles.

These results show that the procedure for locating transects will adequately represent spawning habitat.

5.5 Hydrologic Analyses

5.5.1 Hydrologic analysis concepts

To apply the IFIM methodology to any specific stream, hydrology must be developed to describe the flows that occur there. The flows were estimated using data for certain nearby existing or discontinued USGS stream gages. The stream gage data also were used to monitor existing flow conditions. These monitoring flow levels were very important in determining when to dispatch field crews to sample the stream in a specific flow range.

Criteria for determining when to dispatch field crews were necessary due to different target flow levels required for hydraulic calibration, and rapidly changing conditions at the various sites. These

criteria were necessary to increase the probability of field crews visiting sites at times when the streamflow was in an appropriate range.

The hydrology developed for the study sites included:

- Median monthly flows for all sites for the entire period-of-record;
- Annual mean and median flows for all sites for the entire period-of-record;
- Annual and seasonal flow duration data for all sites for the entire period-of-record; and
- Median monthly flow time series.

5.5.2 Stream gage selection

Stream gages were selected to develop hydrology for study sites, and to determine when to dispatch field crews. To select gages, the study sites were plotted on a stream map (Ings and Simmons, 1991), along with certain long-record gages known to be in the area. These gages were evaluated further, based on drainage area size, proximity, geology, and judgment, to select gages located on streams believed to have hydrology similar to the study sites. Most of the selected gages are currently in operation, but a few have been discontinued. In most cases, one gage was selected for each study site. In a few cases, more than one gage was selected, because of uncertainty regarding the representativeness of the gage, and to provide a backup in the event of an outage.

For certain streams, the hydrology did not correspond with flows measured in the field. As a result, certain changes were made in the original gage selections to provide reasonable correspondence with the flows measured in the field.

In most cases, satellite data transmission equipment was available at the gages selected to generate study site hydrology, and could be used to determine when to dispatch field crews. If the gage used to determine hydrology for a study stream did not have satellite data transmission equipment, additional gages in the area were selected for monitoring current flow conditions to determine when to dispatch field crews.

A list of gages selected for each study stream is shown in Table 5.15.

5.5.3 Hydrology for study sites

In general, the hydrology for each study site was determined using the gage selected, as described. Study site hydrology was generally derived by multiplying streamflows at the appropriate gage by the ratio of drainage area at the site to drainage area at the gage.

For the following study sites, the hydrology procedures were more complex due to mixed or unusual geology, water supply withdrawals, or wastewater treatment plant (WWTP) discharges.

- Monocacy Creek and Bushkill Creek, Northampton County;
- Cedar Creek and Trout Creek, Lehigh County;
- Nancy Run and Spring Creek, Berks County;
- Letort Spring Run, Trindle Spring Run, and Big Spring Creek, Cumberland County;
- Falling Spring Run, Franklin County;
- Spring Creek and Penns Creek, Centre County;
- Honey Creek and Long Hollow Run, Mifflin County;

Table 5.15. Study Sites and Gages

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Spring Creek	4	1	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
		2	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
		3	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	XC	X
		4	Ridge and Valley Limestone	Centre	Spring Creek at Houserville	XC	X
		4	Ridge and Valley Limestone	Centre	Spring Creek at Axemann	XC	
Penns Creek	3	All	Ridge and Valley Limestone	Centre	Penns Creek at Penns Creek	XC	X
Lick Creek	1		Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
Antes Creek	1		Ridge and Valley Limestone	Lycoming	Spring Creek at Houserville	X	X
Cedar Run	1		Ridge and Valley Limestone	Centre	Spring Creek at Houserville	X	X
Boiling Spring Run	1		Ridge and Valley Limestone	Blair	Frankstown Br. at Williamsburg	X	X
Falling Spring Run	1		Ridge and Valley Limestone	Franklin	Letort Spring Run near Carlisle	XC	X
Potter Creek	1		Ridge and Valley Limestone	Bedford	Spring Creek at Houserville	X	X
Big Spring Creek	1		Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Long Hollow Run	1		Ridge and Valley Limestone	Mifflin	Dunning Creek at Belden	X	X
Honey Creek	1		Ridge and Valley Limestone	Mifflin	Kishacoquillas Creek at Reedsville	XC	X
Little Fishing Creek	1		Ridge and Valley Limestone	Clinton	Spring Creek at Houserville	X	X
Monocacy Creek	3	All	Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	C	X
Bushkill Creek	2	All	Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	C	X
Cedar Creek	1		Ridge and Valley Limestone	Lehigh	Monocacy Creek at Bethlehem	XC	X
Trout Creek	1		Ridge and Valley Limestone	Lehigh	Monocacy Creek at Bethlehem	C	X
Spring Creek	1		Ridge and Valley Limestone	Berks	Monocacy Creek at Bethlehem	C	X
Spring Creek	1		Ridge and Valley Limestone	Berks	Maiden Creek at Virginville		X
Trindle Spring Run	1		Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Letort Spring Run	2	All	Ridge and Valley Limestone	Cumberland	Letort Spring Run near Carlisle	XC	X
Nancy Run	1		Ridge and Valley Limestone	Northampton	Monocacy Creek at Bethlehem	XC	X
Cedar Run	1		Ridge and Valley Limestone	Cumberland	Yellow Breeches at Camp Hill	X	X

* Hydrology Key:
- X Hydrology based on drainage area ratio
- XC Hydrology based on gage shown, but more complex than drainage area ratio
- C Complex synthesis procedure, multiple gages

Table-5.15. Study Sites and Gages —Continued

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Wapwallopen Creek	4	All	Ridge and Valley Freestone	Luzerne	Wapwallopen Creek near Wapwallopen	XC	
Wapwallopen Creek	4	All	Ridge and Valley Freestone	Luzerne	Fishing Creek near Bloomsburg		X
Salem Creek	1	All	Ridge and Valley Freestone	Luzerne	Wapwallopen Creek near Wapwallopen	XC	
Salem Creek	1	All	Ridge and Valley Freestone	Luzerne	Fishing Creek near Bloomsburg		X
Mugser Run	2	All	Ridge and Valley Freestone	Columbia	Wapwallopen Creek near Wapwallopen	XC	
Mugser Run	2	All	Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg		X
E. Branch Raven Creek	1		Ridge and Valley Freestone	Columbia	Wapwallopen Creek near Wapwallopen	XC	
E. Branch Raven Creek	1		Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg		X
Green Creek	3	All	Ridge and Valley Freestone	Columbia	Fishing Creek near Bloomsburg	X	X
Big Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Juniata	Kishacoquillas Creek at Reedsville		X
Granville Run	1		Ridge and Valley Freestone	Mifflin	Shermans Creek at Shermans Dale	X	X
Laurel Run	1		Ridge and Valley Freestone	Huntingdon	Aughwick Creek near Three Springs	X	X
Kansas Valley Run	1		Ridge and Valley Freestone	Perry	Shermans Creek at Shermans Dale	X	X
Fowler Hollow Run	2	All	Ridge and Valley Freestone	Perry	Shermans Creek at Shermans Dale	X	X
Broad Run	1		Ridge and Valley Freestone	Franklin	Shermans Creek at Shermans Dale	X	X
Horning Run	1		Ridge and Valley Freestone	Juniata	Shermans Creek at Shermans Dale	X	X
Sand Spring Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Sand Spring Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Rapid Run	3	All	Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Rapid Run	3	All	Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Swift Run	1		Ridge and Valley Freestone	Mifflin	Sand Spring Run near White Deer	X	
Swift Run	1		Ridge and Valley Freestone	Mifflin	Penns Creek at Penns Creek		X
Big Fill Run	1		Ridge and Valley Freestone	Blair	Bald Eagle Creek at Tyrone	X	
Big Fill Run	2	All	Ridge and Valley Freestone	Blair	Frankstown Branch at Williamsburg		X
Bear Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Bear Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X
Vanscoyoc Run	1		Ridge and Valley Freestone	Blair	Bald Eagle Creek at Tyrone	X	
Vanscoyoc Run	1		Ridge and Valley Freestone	Blair	Frankstown Branch at Williamsburg		X
Mile Run	1		Ridge and Valley Freestone	Union	Sand Spring Run near White Deer	X	
Mile Run	1		Ridge and Valley Freestone	Union	Penns Creek at Penns Creek		X

* Hydrology Key: X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

Table 5.15. Study Sites and Gages—Continued

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Tannery Hollow	1		Unglaciated. Plateau	Cameron	Driftwood Branch at Sterling Run	X	X
Whitehead Run	1		Unglaciated Plateau	Cameron	Driftwood Branch at Sterling Run	X	X
Benner Run	1		Unglaciated Plateau	Centre	Marsh Creek at Blanchard	X	
Benner Run	1		Unglaciated Plateau	Centre	Bald Eagle Creek at Milesburg		X
Benner Run	1		Unglaciated Plateau	Centre	Clearfield Creek at Dimeling		X
Meyers Run	1		Unglaciated Plateau	Centre	Marsh Creek at Blanchard	X	
Meyers Run	1		Unglaciated Plateau	Centre	Bald Eagle Creek at Milesburg		X
Meyers Run	1		Unglaciated Plateau	Centre	Clearfield Creek at Dimeling		X
Mill Run	1		Unglaciated Plateau	Clinton	Marsh Creek at Blanchard	X	
Mill Run	1		Unglaciated Plateau	Clinton	Bald Eagle Creek at Milesburg		X
Strange Hollow	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Lyman Run	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Dunlap Run	1		Unglaciated Plateau	Clearfield	Clearfield Creek at Dimeling	X	X
Bloomster Hollow	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
Warner Branch	1		Unglaciated Plateau	McKean	Potato Creek at Smethport	X	X
E. Branch Spring Creek	2	All	Unglaciated Plateau	Elk	W. Branch Clarion at Wilcox	X	X
Cherry Run	1		Unglaciated Plateau	Forest	W. Branch Clarion at Wilcox	X	X
Seaton Run	1		Unglaciated Plateau	Jefferson	W. Branch Clarion at Wilcox	X	X
Lower Two Mile Run	2	All	Unglaciated Plateau	Venango	Oil Creek at Rouseville	X	X
Beech Run	1		Unglaciated Plateau	Clearfield	Mahoning Creek at Punxsutawney	X	X
McEwen Run	1		Unglaciated Plateau	Jefferson	Mahoning Creek at Punxsutawney	X	X
Rattlesnake Run	1		Unglaciated Plateau	Jefferson	Mahoning Creek at Punxsutawney	X	X
Coke Oven Hollow	1		Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Whites Creek	2	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Red Run	1		Unglaciated Plateau	Cambria	Blacklick Creek at Josephine	X	X
Findley Run	1		Unglaciated Plateau	Indiana	Blacklick Creek at Josephine	X	X
Fall Creek	2	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
McClintock Run	1	All	Unglaciated Plateau	Somerset	Laurel Hill Creek at Ursina	X	X
Cush Creek	2	All	Unglaciated Plateau	Indiana	W. Branch Susquehanna River at Bower	X	X

* Hydrology Key: X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

Table 5.15. Study Sites and Gages—Continued

Study Stream	No. Seg.	Seg. No.	Region	County	Gage	Use	
						Hydrology*	Tracking Flows/ Dispatching Crew
Baisman Run	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Basin Run	2		Piedmont Upland	Cecil	Basin Run at Liberty Grove	X	
Cooks Branch	1		Piedmont Upland	Baltimore	Beaver Run near Finksburg	X	
First Mine Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Gillis Falls	2		Piedmont Upland	Carroll	North Br. Patapsco River at Cedarhurst	X	
Greene Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Norris Run	1		Piedmont Upland	Carroll	Beaver Run near Finksburg	X	
Piney Run	1		Piedmont Upland	Baltimore	North Br. Patapsco River at Cedarhurst	X	
Third Mine Branch	1		Piedmont Upland	Baltimore	Little Falls at Blue Mount	X	
Timber Run	1		Piedmont Upland	Baltimore	Beaver Run near Finksburg	X	

* Hydrology Key:
X Hydrology based on drainage area ratio
XC Hydrology based on gage shown, but more complex than drainage area ratio
C Complex synthesis procedure, multiple gages

- Boiling Spring Run, Blair County;
- Potter Creek, Bedford County;
- Wapwallopen Creek and Salem Creek, Luzerne County;
- Mugser Run and East Branch Raven Creek, Columbia County; and
- Red Run, Cambria County.

The procedures for developing hydrology used for these sites are described in Appendix D.

5.5.4 Criteria for dispatching field crews

The determination of when to send out field crews was complicated by:

- The flow range criteria described in section 5.3.3; and
- Different flow conditions occurring in different study streams at a given time, e.g., one study stream in an area might be at a high flow, another stream at a low flow.

The flow relationships and targets shown in Table 5.7 were used to determine which data set(s) had been collected and which remained to be collected. Then the current flows at the tracking gage (Table 5.15) were compared to the appropriate threshold flow to determine whether to dispatch field crews to a particular study stream.

A spreadsheet was developed to facilitate tracking flows, to determine what flows remained to be measured, and when to dispatch field crews. The computation of target measurement flows, the determination of whether the target flow had been measured, the current flows at the study site, and the determination of whether the current flows were in the appropriate range were all programmed into the spreadsheet. The determination of whether flows were in the appropriate range was generally based on real-time data for the appropriate gage and a drainage area ratio.

5.6. Hydraulic Modeling

The PHABSIM computer programs, described by Milhous and others (1989), were used in the hydraulic model calibration and habitat modeling.

5.6.1 Data input and checking procedures

The purpose of the data input checking process was to ensure that the data collected and recorded in the field were accurately entered into the computer file used for hydraulic and habitat modeling.

CDS information (channel and overbank geometry, substrate and cover, flow rate and associated average water surface elevation, and velocity distribution) for each transect at all study sites was manually keyed into a computer data file using the PHABSIM data input routine. Then another PHABSIM routine was used to insure all information was properly located and formatted in the file, and that the data were consistent. A formatted listing of the input file was then manually compared to the original field data sheets to insure the data were correct.

In general, the field data for the PDSs were not entered into the computer file. However, velocity distribution data for the high flow partial data sets were entered and checked.

5.6.2 Hydraulic model calibration

Various hydraulic modeling options are available within PHABSIM, including a routine that uses Manning's equation to simulate water surface elevations (MANSQ) and a routine that uses a rating curve to estimate mean velocity at different flows from water surface elevations (IFG4). In this study, these routines were used to develop a representative hydraulic model for each study site. The hydraulic model(s) were then used to compute water surface elevations and associated velocity distributions at each study site for any flow that was chosen for habitat modeling.

The MANSQ routine develops a stage-discharge curve at each transect, based on a form of Manning's equation (Chow, 1959; Bovee, 1982):

$$Q = \frac{1.49}{n} S^{1/2} AR^{2/3} = KAR^{2/3}$$

where: n = roughness factor;
A = wetted area of the transect;
R = hydraulic radius (area divided by wetted perimeter);
S = slope of stream; and
K = conveyance factor.

The program utilizes the water surface elevation and discharge measured as part of the CDS, and computes other water surface elevations at selected discharges. The computed water surface elevations are based on the channel conveyance factor. The appropriate conveyance factor for each transect is developed by iteratively attempting to match the computed water surface elevations with measured water surface elevations and discharges collected as part of the PDSs (section 5.3.2).

The iterative process to determine the value of the conveyance factor that best fit the computed and observed water surface elevations required numerous computer simulations. In general, three sets of observed water surface elevations at significantly different flows were used for calibration purposes whenever possible. However, because of small differences between maximum and minimum median monthly flows (section 5.3.2) for some streams in the Ridge and Valley Limestone study region, only two data sets were used in the calibration for those streams.

The goal of the calibration process was to match computed and observed water surface elevations exactly. However, because that goal was often unattainable, the calibration process resulted in the value of the conveyance factor that minimized the difference between calculated and observed water surface elevations at each transect. Differences less than, or equal to, 0.1 ft were considered acceptable; differences greater than 0.1 ft required additional analyses to either reduce the difference or explain the reason for the difference.

Field data were collected for a total of 101 study segments in the four study regions (Table 5.5). During the calibration process, the following study sites were eliminated due to insufficient consistent field data to develop an adequate hydraulic model: Broad Run (Franklin County); East Branch Spring Creek (Elk County), segment 1; Rattlesnake Run (Jefferson County); and Whitehead Run (Cameron County). The first stream is in the Ridge in Valley Freestone study region, and the remaining streams are in the Unglaciated Plateau study region.

After the remaining study streams were calibrated, an acceptable hydraulic model was available for 254 individual transects, located at 97 different study sites. Sixteen transects out of a total of 254 were calibrated, although one of the calibration elevations did not match the observed field data within 0.1 ft. The differences ranged from 0.11 ft to 0.31 ft, with an average of 0.18 ft. These 16 transects were considered acceptable, and were used, even though one field data point was not within 0.1 ft of the calibrated flow.

Possible explanations for these discrepancies include:

- Leaf accumulation in the stream channel could have affected the observed water surface elevation;
- Undetected survey errors may have occurred;
- Benchmarks may have been disturbed;
- Seasonal variations in aquatic vegetation may have impacted the flow regime; or
- High water conditions, or other factors, occurring between the collection of data sets, may have caused changes in stream geometry.

Aquatic vegetation problems were acute in the Ridge and Valley Limestone study region, where 50 percent of the unresolved calibration problems occurred. The aquatic vegetation effect was not discovered until well into the data collection and calibration phases of the study.

A summary of the sites remaining after completion of the model calibration phase is shown in Table 5.16. This table is comparable to Table 5.5, which shows a summary of sites prior to the modeling phase. However, the data are compiled differently. The number of study streams with a certain number of segments are shown in Table 5.5, but the number of segments in each segment class are shown in Table 5.16. For example, a three-segment stream is counted as such, and included only in column four of Table 5.5. A three-segment stream has one segment in each of the first three classes, and is shown in each of columns 2 through 4 of Table 5.16. The reason for this change is that subsequent analyses group all segments in a given class.

Table 5.16. Summary of Study Sites After Hydraulic Calibration

Study Region	Number of Final Study Sites				Total Number of Segments
	Segment Class One	Segment Class Two	Segment Class Three	Segment Class Four	
Ridge and Valley Limestone	21	5	3	1	30
Ridge and Valley Freestone	19	6	3	1	29
Unglaciated Plateau	21	5	—	—	26
Piedmont Upland	10	2	—	—	12
Grand Total	71	18	6	2	97

5.7 Physical Microhabitat Estimation

The PHABSIM protram includes several habitat modeling routines. In this study, the HABTAE routine was used. This routine computes WUA per 1,000 feet of stream length for each transect, for each level of flow, and for each evaluation species and life stage. The amount of WUA is computed from HSC, transect geometry, mean column velocity, and transect reach lengths expressed as a percent of each mesohabitat type, determined as described in section 5.3.1.

After the hydraulic models were calibrated for the 97 study sites (section 5.6.2), the available habitat was estimated using the HABTAE routine. WUA was computed for adult, juvenile, fry, and spawning life stages for each evaluation species, brook trout, brown trout and combined brook and brown trout.

The habitat modeling included the following steps:

- Selection of flows to be simulated for each study site;
- Simulation of water surface elevations and velocity distributions for each flow at each study site and transect; and
- Computation of the available habitat for each flow at each study site and transect for each evaluation species and life stage, using the HABTAE routine in PHABSIM.

Eighteen different simulation flows were selected at each site, based on statistical analysis of the 12 median monthly flows at each site, estimated as described in section 5.5. This statistical analysis gave values for the minimum, maximum, and 25th, 50th, and 75th percentile median monthly flows at each site. Thirteen additional values were calculated from these five values, emphasizing the lower end of the expected flow range, as follows:

- Three simulation flows less than the minimum median monthly flow;
- Four flows between the minimum median monthly flow and the 75 percent probability of exceedance value;
- Two flows between the 75 and 50 percent probability of exceedance;
- Two flows between the 50 and 25 percent probability of exceedance;
- One flow between the 25 percent probability of exceedance and the maximum median monthly flow; and
- One flow greater than the maximum median monthly flow.

These 18 flows were checked to insure they were within the acceptable model flow range discussed in section 5.3.3. If any simulation flows fell outside the model flow range, the simulation values were modified to insure they would not violate the maximum extrapolation limits described in section 5.3.3.

The previously-calibrated hydraulic models for each cell of each transect were used to simulate water surface elevations for each flow selected, using the MANSQ routine. The computed water surface elevations were used to calculate a velocity distribution for each simulation flow across each transect, using the IFG4 routine. That routine adjusts the observed water surface elevation and associated velocity distribution across the transect (collected as part of the CDS) to determine a velocity distribution that corresponds to each simulated flow and water surface elevation. The result is a water surface elevation and velocity distribution table for each transect for each of the 18 simulation flows.

The input to the HABTAE routine included the following:

- The water surface elevation/velocity distribution table;
- Percentage length of each mesohabitat type determined from the length of each mesohabitat type, collected as part of the complete data set (section 5.3.1);
- HSC for the evaluation species and life stage being analyzed, developed as described in sections 3.7; and
- All of the original transect geometry and substrate data.

The HABTAE routine generates a table of WUA versus discharge for the study site for each species and life stage. An example of these tables is shown in Table 5.17. The simulation is repeated for each life stage of each evaluation species being considered.

5.8 Comparison of Univariate and Binary Suitability Criteria

5.8.1 Purpose of comparing alternative criteria

Because univariate habitat suitability criteria such as described in sections 3.7 may result in protecting low quality habitat, Bovee and others (1994) recommend consideration of the use of binary, rather than univariate curves, in microhabitat simulations. The difference between the two types of criteria is that univariate criteria can have values that range from 1 to 0, as shown in Figures 3.9 through 3.16, but binary criteria can only have a value of either 1 or 0. Univariate curves have been almost universally used in IFIM studies involving brook and brown trout. No binary criteria for brook or brown trout were identified for transferability testing at the time this study was initiated.

Binary criteria were developed from the new univariate HSC (section 3.7), and a pilot study was performed to evaluate the potential effects of using binary criteria for this study

5.8.2 Development of binary criteria

There are no established methods for converting univariate criteria to binary criteria. The shape of the univariate curves shown in Figures 3.9 through 3.16 was examined to establish the cutoff for optimum habitat for use in developing binary criteria. Some of the univariate curves have sharp peaks, resulting in only a narrow range of depths or velocities for the greater HSC index values. For that reason, binary criteria for depth and velocity were developed by assigning the binary criteria value of 1 to all univariate suitability index values equal to, or greater than, 0.7. All univariate suitability index values less than 0.7 were assigned the binary criteria value of 0. The same procedure was used to develop binary substrate/cover criteria for brook and brown trout juveniles, spawning, and fry.

If the same procedure had been used to develop binary substrate/cover criteria for adults, the only habitat with any value (binary criteria value of 1) would have been that associated with undercut objects along stream banks. As shown in Table 3.7, all other habitat would have been assigned the binary criteria value of 0. Because brook and brown trout adults in the transferability study streams used other types of cover when it was available, cover types 2 (object cover), 3 (undercut object along bank), 4 (aquatic vegetation), and 5 (terrestrial vegetation less than 1 foot above water surface) were assigned the binary criteria value of 1. Cover type 1 (no cover) was assigned the binary criteria value of 0 for brook and brown trout adults.

5.8.3 Pilot study procedures and results

The purpose of the pilot study was to compare the difference in habitat (WUA) values resulting from the different types of criteria. The pilot study was conducted at four study sites in each of three study regions, with a range of drainage areas to minimize bias. WUA versus discharge relationships for both sets of criteria were plotted, and evaluated subjectively. In all cases, the univariate criteria produced a smooth, steadily increasing or decreasing plot of habitat versus flow, whereas the binary criteria plots showed significant variability, sometimes a saw-tooth pattern. Comparisons of the WUA curves for Bloomster Hollow (Unglaciated Plateau study region) for each type of criteria and each life stage are

Table 5.17. Example of Habitat Output, Green Creek, Segment 1, Ridge and Valley Limestone Study Region

	DISCHARGE	AREA
* 1	0.42	9275.05
* 2	0.53	9506.83
* 3	0.65	9762.35
* 4	0.76	10023.77
* 5	0.86	10104.15
* 6	0.97	10160.23
* 7	1.07	10259.48
* 8	1.18	10330.73
* 9	1.28	10411.09
*10	1.80	10708.92
*11	2.32	10962.97
*12	2.84	11087.59
*13	3.10	11130.77
*14	3.37	11192.94
*15	3.63	11246.69
*16	4.91	11490.02
*17	6.18	11648.83
*18	7.42	11826.97

****

BROOK TROUT

	DISCHARGE	ADULT	JUVENILE	SPAWNING	FRY
* 1	0.42	664.72	1766.67	1001.39	1726.70
* 2	0.53	721.55	1878.57	1066.90	1710.23
* 3	0.65	796.02	2031.52	1155.62	1723.81
* 4	0.76	849.33	2158.53	1236.56	1743.60
* 5	0.86	892.00	2234.56	1290.77	1716.47
* 6	0.97	939.83	2318.00	1328.13	1683.01
* 7	1.07	990.77	2428.81	1379.91	1685.53
* 8	1.18	1018.35	2496.07	1412.77	1662.13
* 9	1.28	1060.61	2578.90	1450.34	1637.70
*10	1.80	1205.83	2909.19	1551.68	1553.12
*11	2.32	1336.82	3175.69	1635.44	1511.73
*12	2.84	1433.29	3356.81	1672.94	1392.18
*13	3.10	1456.89	3400.47	1676.07	1360.04
*14	3.37	1505.50	3484.10	1692.68	1329.86
*15	3.63	1536.59	3547.27	1706.22	1302.04
*16	4.91	1656.49	3640.53	1754.76	1234.77
*17	6.18	1740.94	3680.77	1693.78	1203.68
*18	7.42	1849.11	3742.42	1643.97	1143.86

shown in Figure 5.6, and illustrate the behavior of the different types of criteria. All 12 study sites used in this pilot study showed similar behavior.

Although the concept of using only the optimum habitat seems intuitively reasonable, the shapes of the curves, and the low amount of habitat available on streams with excellent trout populations, made interpretation of the binary curves difficult. The WUA curves based on univariate criteria appeared to be more consistent with expected flow versus habitat relationships. Perhaps the reason is that suboptimal habitat is very important to the populations. For that reason, the analysis of habitat impacts was based on univariate criteria.

5.9 Wetted Perimeter Analysis

As discussed in section 2.1.1.2, the wetted perimeter method is usually applied to riffle transects, because those transects are considered most critical for protecting macroinvertebrate populations. The wetted perimeter method was applied to each riffle transect measured during the study. Because some study sites did not have any riffle habitat, only 91 riffle transects were analyzed, 12 in the Piedmont Upland study region, 25 in the Unglaciated Plateau study region, 26 in the Ridge and Valley Limestone study region, and 28 in the Ridge and Valley Freestone study region.

For each riffle transect, wetted perimeter at the simulation discharges was plotted versus flow, and the inflection point was determined visually. In effect, this procedure assumes that the inflection point is within the range of the simulation flows.

Definite inflection points could be identified for only 47 study sites and transects. Examples of definite inflection points are shown in Figures 5.7 and 5.8. The graphs for the remaining transects showed one of the following:

- Either a straight line or a smooth curve with no discernible inflection points, as illustrated in Figures 5.9 and 5.10;
- A slight change in curvature, resulting in a marginal selection of the inflection point, as illustrated in Figure 5.11; or
- Two distinct inflection points, as illustrated in Figure 5.12.

A summary of the number of segments showing each type of plot is shown in Table 5.18.

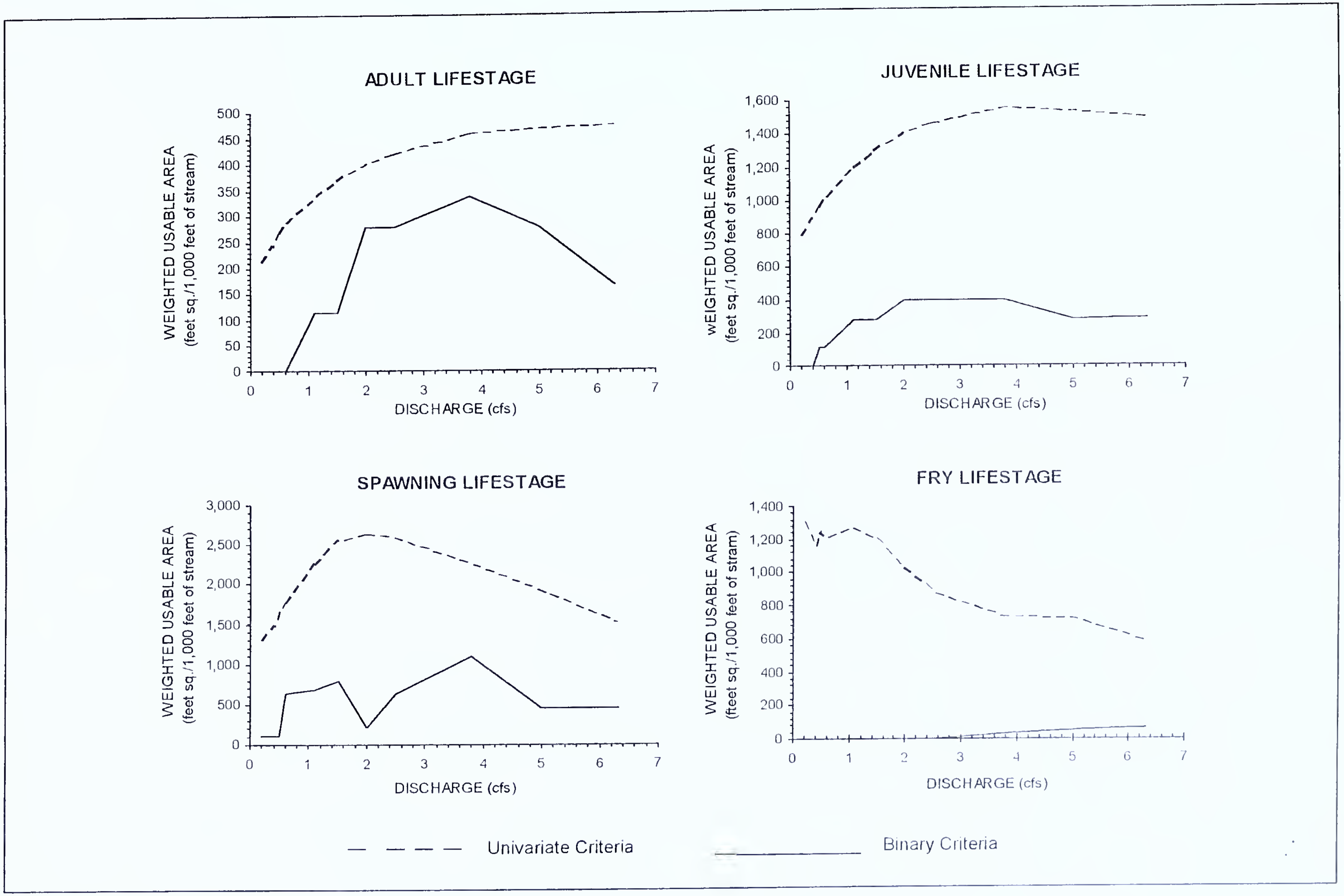

Figure 5.6. Comparison of Weighted Usable Area for Alternative Habitat Suitability Criteria

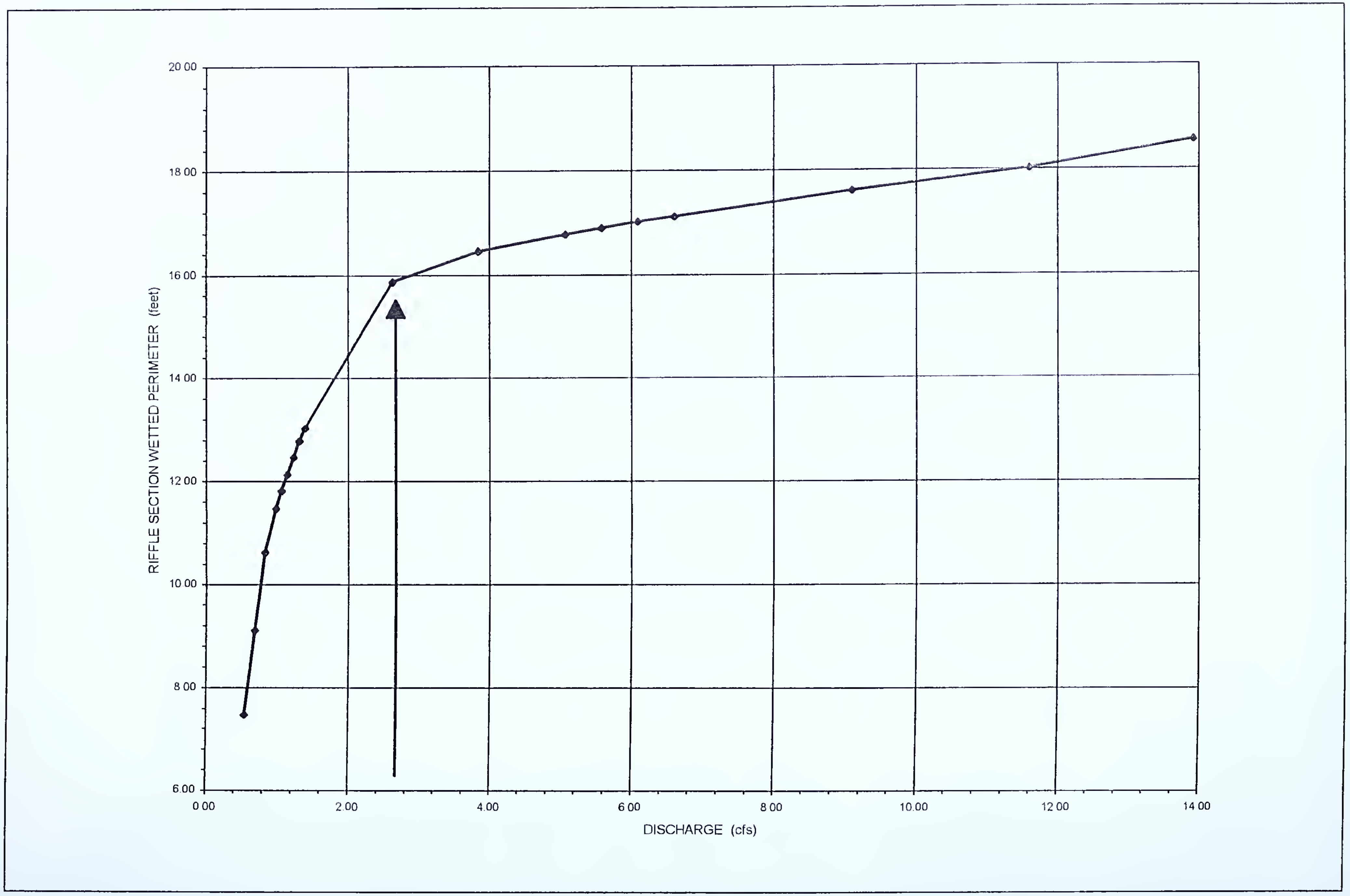

Figure 5.7. Typical Wetted Perimeter Plot With Definite Inflection Point (Unglaciated Plateau Study Region, Fall Creek, Segment 1)

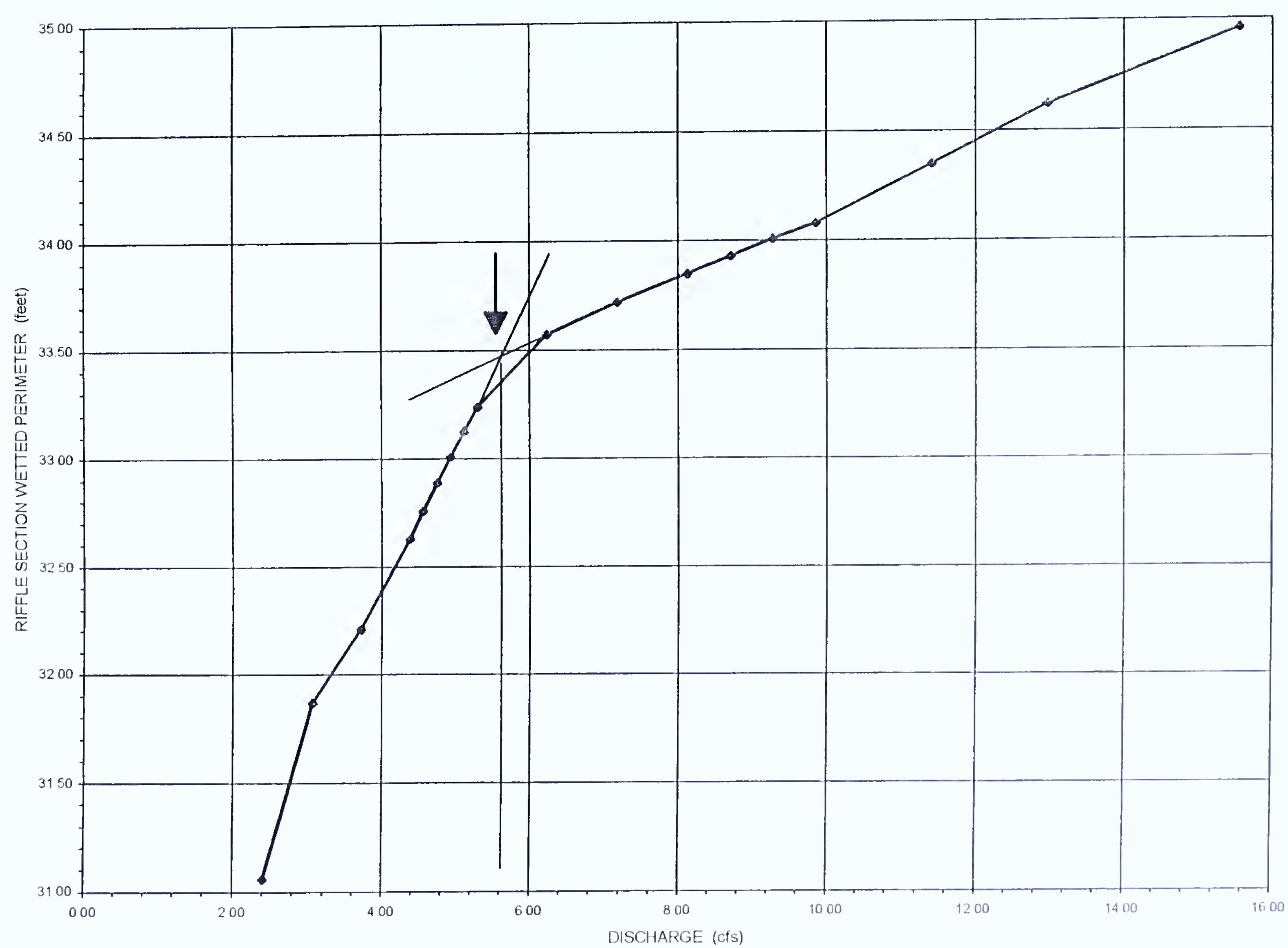

Figure 5.8. Typical Wetted Perimeter Plot With Definite Inflection Point (Piedmont Upland Study Region, Basin Run, Segment 2)

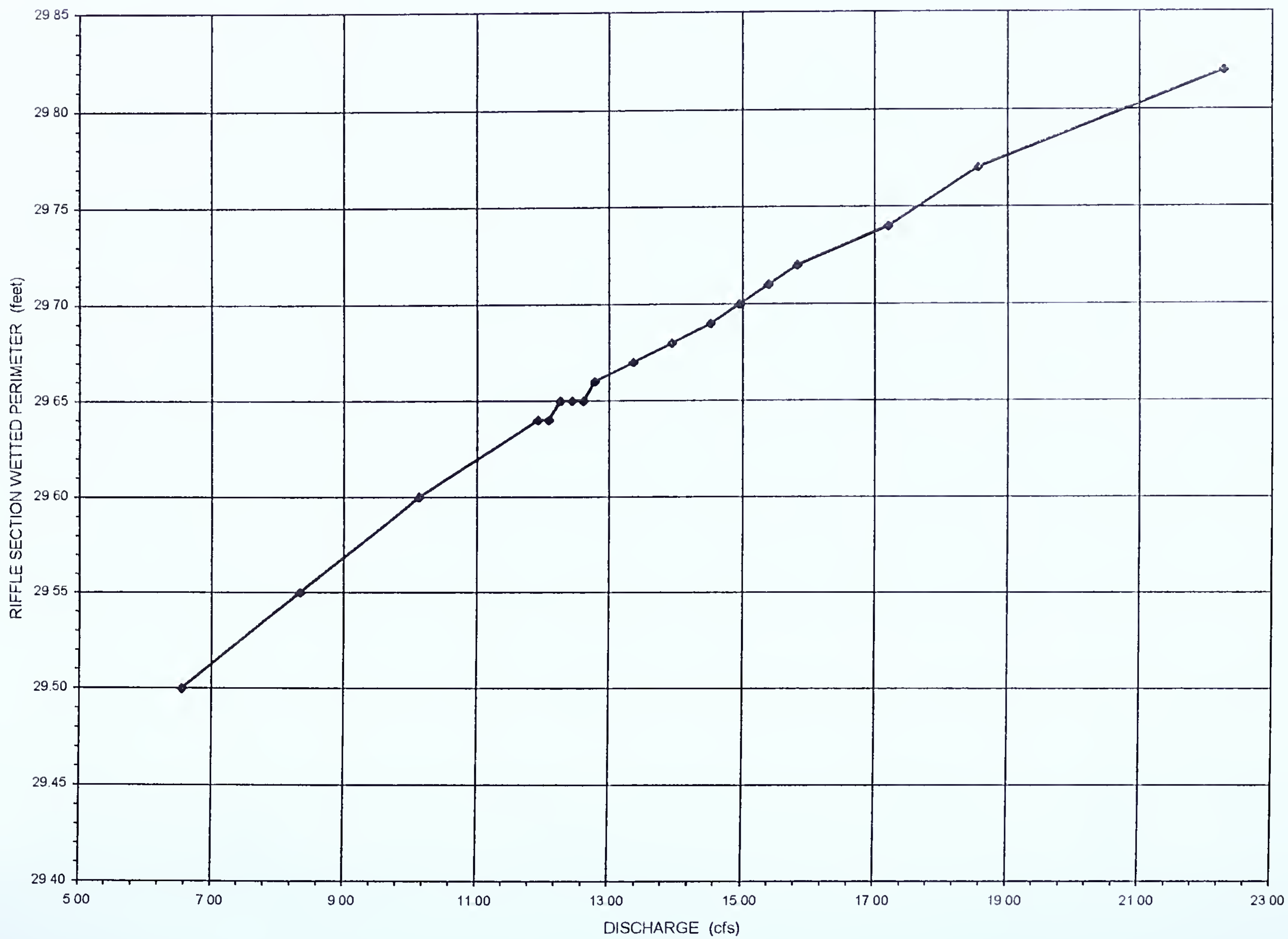

Figure 5.9. Typical Wetted Perimeter Plot With No Inflection Point (Ridge and Valley Limestone Study Region, Cedar Creek, Lehigh County, Segment 1)

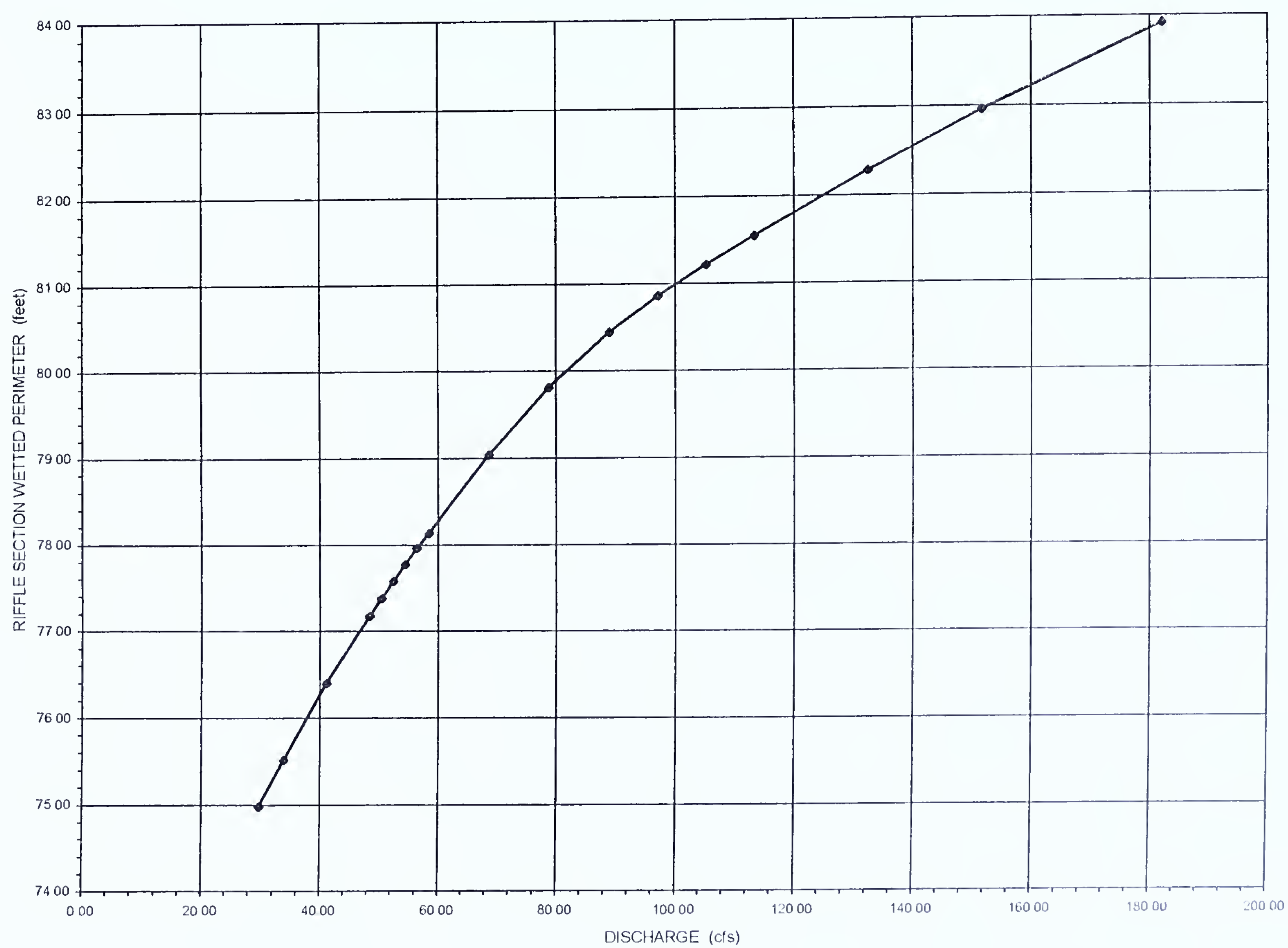

Figure 5.10. Typical Wetted Perimeter Plot With No Inflection Point (Ridge and Valley Limestone Study Region, Bushkill Creek, Segment 2)

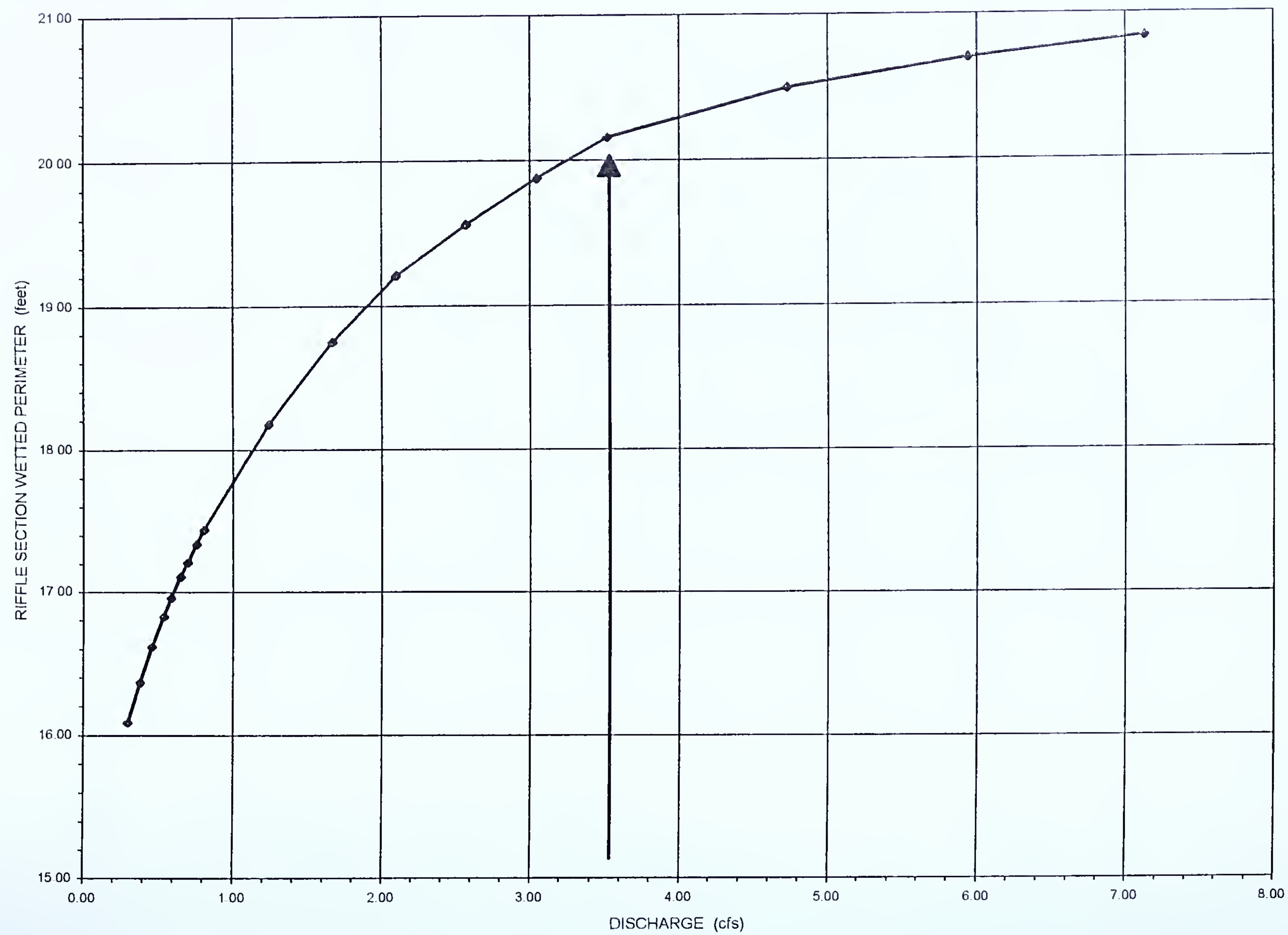

Figure 5.11. Typical Wetted Perimeter Plot With Marginal Inflection Point (Ridge and Valley Freestone Study Region, Big Run, Segment 1)

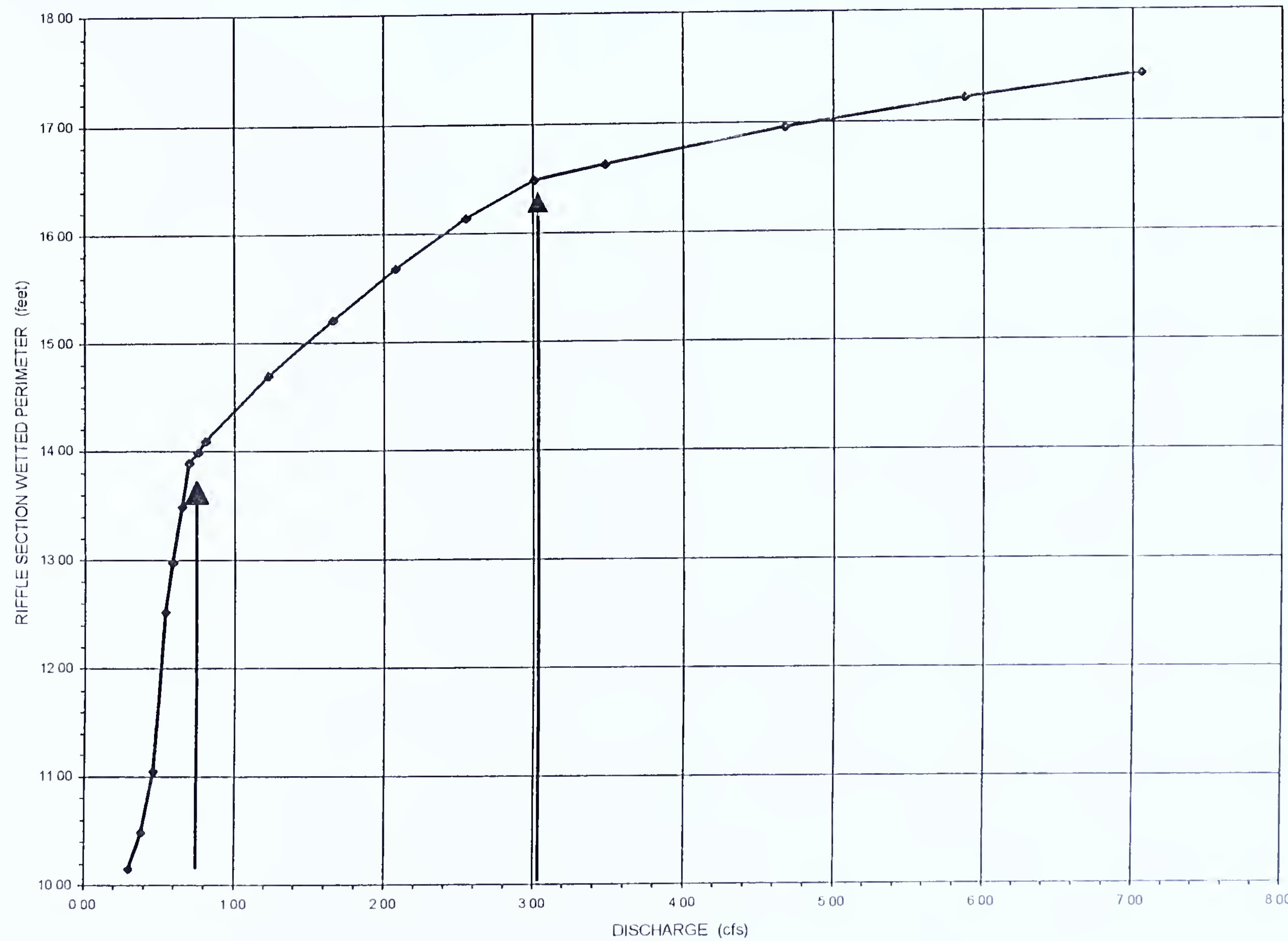

Figure 5.12. Typical Wetted Perimeter Plot With Two Inflection Points (Ridge and Valley Freestone Study Region, Laurel Run, Juniata County, Segment 1)

Table 5.18. Number of Sites Showing Different Wetted Perimeter Curve Types

Wetted Perimeter Curve Type	All Study Regions	Ridge and Valley Limestone	Ridge and Valley Freestone	Unglaciated Plateau	Piedmont Upland
Definite Inflection Point	47	14	14	15	4
No Inflection Point	23	9	5	4	5
Marginal Inflection Point	12	2	3	4	3
Double Inflection Point	9	1	6	2	0
Total	91	26	23	25	12

The flows at the inflection points were tabulated by region and expressed as a unit flow rate (csm) and as a percent of ADF. For transects where two inflection points were identified, the lower flow value was included in the table. The averages and standard deviations of both the unit flow rates and the percent ADF values were computed for all the transects within a region where inflection points could be identified. These tabulations are shown in Tables 5.19 through 5.22.

The averages and standard deviations of the unit flow rates and the percent ADF values also were computed for only the transects that displayed definite inflection points. These computations are not included in this report. However, comparison of this case with the results shown in Tables 5.19 through 5.22 showed that excluding study sites with no definite inflection point changed the regional average of the unit flow rates (csm) at the inflection point by as much as 0.12 csm, depending on region. Also, the regional average percentage of ADF changed by as much as 6.3 percent, depending on region. Since these changes were well within one standard deviation of the inflection point values for the respective regions, shown in Tables 5.19 through 5.22, they were considered insignificant. Also, there was no consistency in direction of change.

Because these wetted perimeter plots were developed only for the range of simulation flows, they did not include zero flow. The curves were extended to include the point at zero wetted perimeter and zero flow, as illustrated in Figures 5.13 and 5.14. These figures show that including the "zero-zero" point in the wetted perimeter versus flow plot changes the graph substantially, and usually introduces a lower inflection point, depending on channel geometry. The resulting inflection points for the Ridge and Valley Freestone, Unglaciated Plateau, and Piedmont Upland study regions are summarized in Table 5.23 through 5.25.

The conclusion was that wetted perimeter data developed from the limited range of simulation flows are not adequate to allow selection of inflection points. Therefore, comparisons with the results of the IFIM method are not possible without collecting additional extreme low flow data.

Table 5.19. Wetted Perimeter Summary, Ridge and Valley Freestone Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point			
		sq. mi.	cfs	cfs		csm	% ADF
Bear Run	1	2.19	4.12	1.50		0.68	36.41
Big Fill Run	2	12.12	20.91	None			
Big Run	1	2.88	4.10	3.50	M	1.22	85.37
E. Branch Raven Creek	1	2.48	3.63	None			
Fowlers Hollow Run	1	1.81	2.58	1.15		0.64	44.57
Fowlers Hollow Run	2	5.52	7.87	4.40		0.80	55.91
Granville Run	1	2.74	3.90	0.78		0.28	20.00
Green Creek	1	2.55	4.44	0.78	D	0.31	17.57
Green Creek	2	9.42	16.40	3.20	D	0.34	19.51
Green Creek	3	33.24	57.87	10.00	D	0.30	17.28
Horning Run	1	5.26	7.50	2.55		0.48	34.00
Kansas Valley Run	1	2.91	4.15	0.80		0.27	19.28
Laurel Run (Huntingdon County)	1	1.50	1.76	0.17	D	0.11	9.66
Laurel Run (Juniata County)	1	2.85	4.06	0.72	D	0.25	17.73
Mile Run	1	1.37	2.58	2.22		1.62	86.05
Mugser Run	1	4.39	6.42	2.35	M	0.54	36.60
Mugser Run	2	8.92	13.05	5.00		0.56	38.31
Rapid Run	1	3.50	6.59	3.50		1.00	53.11
Rapid Run	2	10.74	20.22	14.50		1.35	71.71
Rapid Run	3	14.53	27.35	8.80	D	0.61	32.18
Salem Creek	1	2.70	3.95	None			
Sand Spring Run	1	3.22	6.06	None			
Swift Run	1	3.03	5.70	3.05		1.01	53.51
Vanscoyoc Run	1	3.36	5.80	2.07		0.62	35.69
Wapwallopen Creek	1	4.13	2.76	None			
Wapwallopen Creek	2	13.90	17.06	12.30		0.88	72.10
Wapwallopen Creek	3	26.82	39.75	28.00	M	1.04	70.44
Wapwallopen Creek	4	33.43	49.42	21.50		0.64	43.50
				Average		0.68	42.20
				Standard Deviation		0.39	22.86

M = Marginal inflection point
D = Double inflection points (lower value shown)

Table 5.20. Wetted Perimeter Summary, Ridge and Valley Limestone Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area sq. mi.	Average Daily Flow cfs	Inflection Point cfs		csm	% ADF
Antes Creek	1	52.00	51.91	None			
Big Spring Creek	1	7.30	35.74	None			
Boiling Spring Run	1	6.30	8.53	1.62		0.26	18.99
Bushkill Creek	1	59.37	85.26	61.00		1.03	71.55
Bushkill Creek	2	79.34	118.21	None			
Cedar Creek (Lehigh)	1	11.58	16.38	None			
Cedar Run (Centre)	1	13.94	13.92	None			
Cedar Run (Cumberland)	1	6.08	8.11	7.05		1.16	86.93
Honey Creek	1	91.45	68.93	28.00		0.31	40.62
Lick Creek	1	10.20	10.18	4.82		0.47	47.35
Little Fishing Creek	1	41.76	41.69	None			
Long Hollow Run	1	6.34	8.40	1.18	D	0.19	14.05
Monocacy Creek	1	8.45	12.13	3.45		0.41	28.44
Monocacy Creek	3	41.56	43.32	21.00		0.51	48.48
Nancy Run	1	5.85	8.62	None			
Penns Creek	1	15.10	19.90	9.98		0.66	50.15
Penns Creek	2	63.50	90.86	34.00		0.54	37.42
Penns Creek	3	89.40	128.79	103.00	M	1.15	79.98
Potter Creek	1	12.55	12.53	5.20	M	0.41	41.50
Spring Creek (Berks)	1	19.68	29.33	14.95		0.76	50.97
Spring Creek (Centre)	1	29.70	29.65	19.60		0.66	66.10
Spring Creek (Centre)	2	58.55	58.45	None			
Spring Creek Centre)	3	79.10	79.47	48.50		0.61	61.03
Spring Creek (Centre)	4	86.30	58.45	89.00		1.03	152.27
Trindle Spring Run	1	19.55	18.92	None			
Trout Creek	1	7.98	12.00	5.30		0.66	44.17
				Average		0.64	55.29
				Standard Deviation		0.30	31.79

M = Marginal inflection point
D = Double inflection points (lower value shown)

Table 5.21. Wetted Perimeter Summary, Unglaciated Plateau Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area sq. mi.	Average Daily Flow cfs	Inflection Point cfs		csm	% ADF
Beech Run	1	1.40	2.45	1.17		0.84	47.76
Benner Run	1	4.38	5.78	2.00		0.46	34.60
Bloomster Hollow	1	1.52	2.90	None			
Cherry Run	1	3.35	6.70	6.82		2.04	101.79
Coke Oven Hollow	1	1.22	2.68	None			
Cush Creek	1	1.99	3.51	1.20	D	0.60	34.19
Cush Creek	2	4.85	8.56	12.60	M	2.60	147.20
Dunlap Run	1	1.20	1.87	1.85		1.54	98.93
E. Branch Spring Creek	2	11.45	22.90	11.20		0.98	48.91
Fall Creek	1	3.41	7.50	2.65		0.78	35.33
Fall Creek	2	5.89	12.95	5.80		0.98	44.79
Findley Run	1	6.17	11.86	15.00	M	2.43	126.48
Lower Two Mile Run	1	2.72	4.91	2.38		0.88	48.47
Lower Two Mile Run	2	8.43	15.20	4.00		0.47	26.32
Lyman Run	1	1.00	1.91	None			
McClintock Run	1	11.77	25.87	10.20		0.87	39.43
McEwen Run	1	2.13	3.73	1.88	M	0.88	50.40
Meyers Run	1	0.47	0.62	0.16		0.33	25.00
Mill Run	1	1.70	2.24	0.69		0.41	30.80
Red Run	1	1.43	1.99	0.69		0.48	34.67
Seaton Run	1	2.40	4.80	None			
Strange Hollow	1	0.88	1.68	0.49		0.56	29.17
Tannery Hollow	1	4.25	7.09	0.80	D	0.19	11.28
Warner Brook	1	3.22	6.14	2.05		0.64	33.39
Whites Creek	2	31.79	69.89	24.50	M	0.77	35.06
				Average		0.94	51.62
				Standard Deviation		0.67	35.63

M = Marginal inflection point
D = Double inflection points (lower value used)

Table 5.22. Wetted Perimeter Summary, Piedmont Upland Study Region (Simulated Flows)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point			
		sq. mi.	cfs	cfs		csm	% ADF
Baisman Run	1	1.33	1.69	1.47	M	1.11	86.98
Basin Run	1	2.08	2.64	None			
Basin Run	2	9.77	12.40	5.70		0.58	45.97
Cooks Branch	1	0.87	0.94	None			
First Mine Branch	1	5.07	6.44	3.65		0.72	56.68
Gillis Falls	1	2.26	2.51	None			
Gillis Falls	2	7.79	8.66	9.25		1.19	106.81
Greene Branch	1	1.14	1.45	0.93		0.82	64.14
Norris Run	1	2.04	2.21	None			
Piney Run	1	5.09	5.66	4.45	M	0.87	78.62
Third Mine Branch	1	0.96	1.22	None			
Timber Run	1	0.29	0.31	0.23	M	0.79	74.19
				Average		0.87	73.34
				Standard Deviation		0.21	20.19

M = Marginal inflection point
D = Double inflection points (lower value shown)

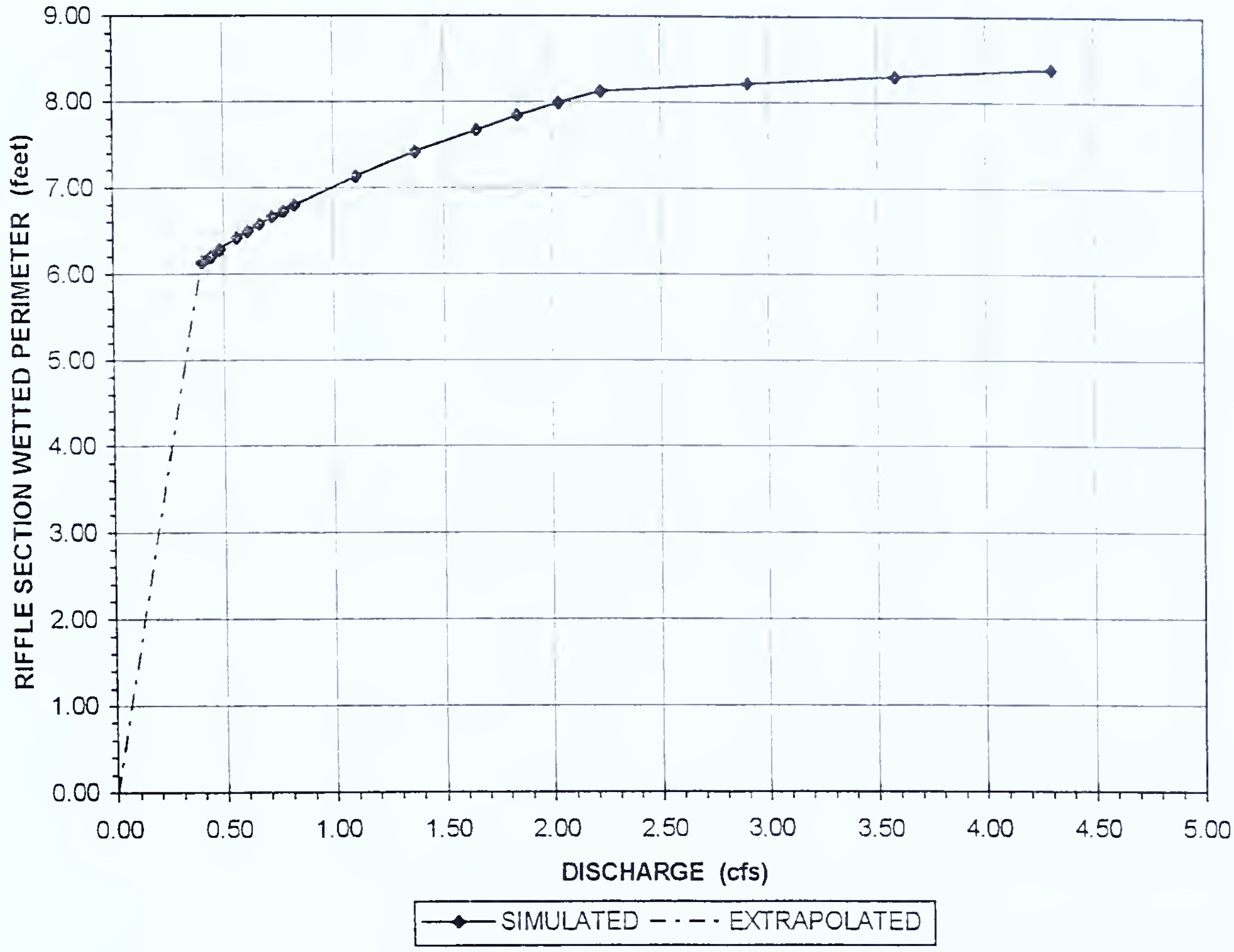

Figure 5.13. Wetted Perimeter Graph Showing Effect of Extrapolation, Mile Run, Segment 1

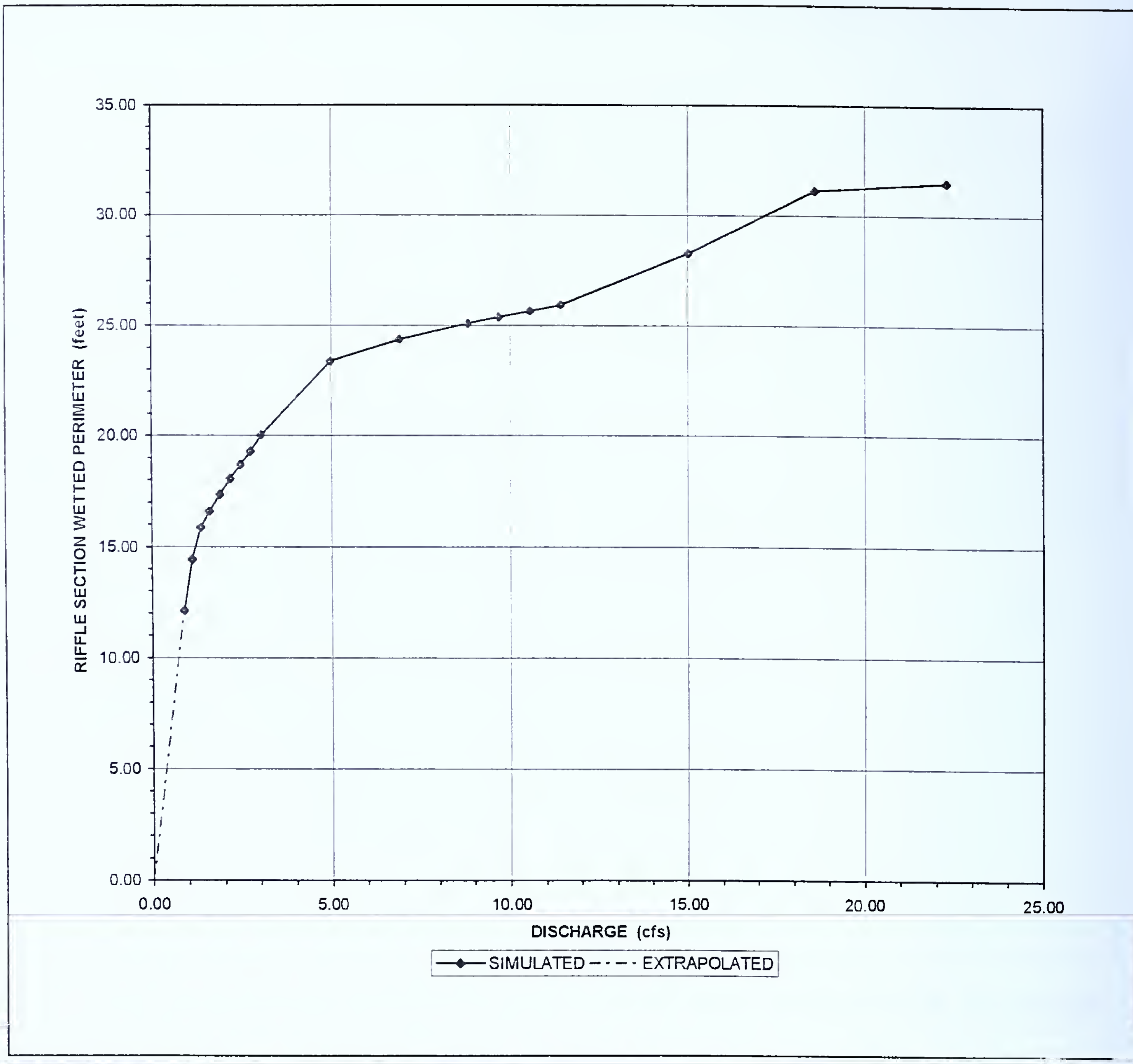

Figure 5.14. Wetted Perimeter Graph Showing Effect of Extrapolation, Mugser Run, Segment 2

Table 5.23. Wetted Perimeter Summary, Ridge and Valley Freestone Study Region (Extrapolated to Zero Flow)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point		
		sq. mi.	cfs	cfs	csm	% ADF
Bear Run	1	2.19	4.12	0.60	0.27	14.56
Big Fill Run	2	12.12	20.91	1.80	0.15	8.61
Big Run	1	2.88	4.10	0.30	0.10	7.31
E. Branch Raven Creek	1	2.48	3.63	0.25	0.10	6.89
Fowlers Hollow Run	1	1.81	2.58	0.35	0.19	13.57
Fowlers Hollow Run	2	5.52	7.87	0.60	0.11	7.62
Granville Run	1	2.74	3.90	0.30	0.11	7.69
Green Creek	1	2.55	4.44	0.78	0.31	17.57
Green Creek	2	9.42	16.40	3.00	0.32	18.29
Green Creek	3	33.24	57.87	5.50	0.17	9.50
Horning Run	1	5.26	7.50	1.00	0.19	13.33
Kansas Valley Run	1	2.91	4.15	0.70	0.24	16.87
Laurel Run (Huntingdon County)	1	1.50	1.76	0.17	0.11	9.66
Laurel Run (Juniata County)	1	2.85	4.06	0.72	0.25	17.73
Mile Run	1	1.37	2.58	0.40	0.29	15.50
Mugser Run	1	4.39	6.42	0.70	0.16	10.90
Mugser Run	2	8.92	13.05	1.30	0.15	9.96
Rapid Run	1	3.50	6.59	0.80	0.23	12.14
Rapid Run	2	10.74	20.22	3.00	0.28	14.84
Rapid Run	3	14.53	27.35	3.20	0.22	11.70
Salem Creek	1	2.70	3.95	0.35	0.13	8.86
Sand Spring Run	1	3.22	6.06	0.75	0.23	12.38
Swift Run	1	3.03	5.70	0.70	0.23	12.28
Vanscoyoc Run	1	3.36	5.80	0.45	0.13	7.76
Wapwallopen Creek	1	4.13	2.76	0.46	0.11	16.67
Wapwallopen Creek	2	13.90	17.06	1.70	0.12	9.96
Wapwallopen Creek	3	26.82	39.75	6.00	0.22	15.09
Wapwallopen Creek	4	33.43	49.42	9.50	0.28	19.22
				Average	0.19	12.37
				Standard Deviation	0.07	3.77

Table 5.24. Wetted Perimeter Summary, Unglaciated Plateau Study Region (Extrapolated to Zero Flow)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point		
		sq. mi.	cfs	cfs	csm	% ADF
Beech Run	1	1.40	2.45	0.22	0.16	8.98
Benner Run	1	4.38	5.78	1.60	0.37	27.68
Bloomster Hollow	1	1.52	2.90	0.30	0.20	10.34
Cherry Run	1	3.35	6.70	0.60	0.18	8.95
Coke Oven Hollow	1	1.22	2.68	0.30	0.25	11.19
Cush Creek	1	1.99	3.51	0.40	0.20	11.40
Cush Creek	2	4.85	8.56	0.80	0.17	9.35
Dunlap Run	1	1.20	1.87	0.15	0.13	8.02
E. Branch Spring Creek	2	11.45	22.90	4.00	0.35	17.47
Fall Creek	1	3.41	7.50	0.80	0.24	10.67
Fall Creek	2	5.89	12.95	2.30	0.39	17.76
Findley Run	1	6.17	11.86	1.30	0.21	26.48
Lower Two Mile Run	1	2.72	4.91	0.92	0.34	18.74
Lower Two Mile Run	2	8.43	15.20	2.00	0.24	13.16
Lyman Run	1	1.00	1.91	0.20	0.20	10.47
McClintock Run	1	11.77	25.87	4.80	0.41	18.55
McEwen Run	1	2.13	3.73	1.35	0.63	36.19
Meyers Run	1	0.47	0.62	0.06	0.13	9.68
Mill Run	1	1.70	2.24	0.60	0.35	26.79
Red Run	1	1.43	1.99	0.10	0.07	5.03
Seaton Run	1	2.40	4.80	0.50	0.21	10.42
Strange Hollow	1	0.88	1.68	0.18	0.21	10.71
Tannery Hollow	1	4.25	7.09	0.80	0.19	11.28
Warner Brook	1	3.22	6.14	2.00	0.62	32.57
Whites Creek	2	31.79	69.89	8.00	0.25	11.45
				Average	0.27	15.31
				Standard Deviation	0.14	8.33

Table 5.25. Wetted Perimeter Summary, Piedmont Upland Study Region (Extrapolated to Zero Flow)

Study Site	Segment Class	Drainage Area	Average Daily Flow	Inflection Point		
		sq. mi.	cfs	cfs	csm	% ADF
Baisman Run	1	1.33	1.69	0.48	0.36	28.40
Basin Run	1	2.08	2.64	0.50	0.24	18.94
Basin Run	2	9.77	12.40	2.40	0.25	19.35
Cooks Branch	1	0.87	0.94	0.20	0.23	21.28
First Mine Branch	1	5.07	6.44	1.80	0.36	27.95
Gillis Falls	1	2.26	2.51	0.60	0.27	23.90
Gillis Falls	2	7.79	8.66	2.00	0.26	23.09
Greene Branch	1	1.14	1.45	0.63	0.55	43.45
Norris Run	1	2.04	2.21	0.45	0.22	20.36
Piney Run	1	5.09	5.66	1.30	0.17	22.97
Third Mine Branch	1	0.96	1.22	0.35	0.37	28.69
Timber Run	1	0.29	0.31	0.07	0.24	22.58
				Average	0.29	25.08
				Standard Deviation	0.10	6.70

6.0 IMPACT ASSESSMENT METHODS AND RESULTS

6.1 Overview of Impact Analysis

The ultimate objective of this instream flow study is to develop an impact assessment method for determining instream flow protection levels during the review of applications for surface water withdrawals. The method needs to include:

- Procedures to analyze the information to determine the protection level;
- Estimation of the effect of a proposed withdrawal; and
- Determination of the type and level of mitigation required.

To evaluate effects of changes in flow on habitat, a procedure was developed for combining the WUA versus flow relationships for each life stage into a single relationship of habitat to flow. The procedure is described in section 6.3. The resulting habitat variable is called renormalized minimum weighted usable area, or RMWUA.

It was decided to use the median monthly habitat as a measure of the habitat available with the natural flow regime. The rationale for using the median monthly habitat was the assumption that the fishery population had adjusted to the amount of habitat naturally available half the time. The median monthly habitat was considered as a benchmark for measuring the impacts of withdrawals and associated passby flows.

Both no-loss of habitat and no-net-loss of habitat at the median monthly flow were considered as possible criteria for determining the level of flow that would protect the median monthly habitat. Neither criterion specifically considers the impact of withdrawals. The no-loss of habitat criterion was determined to unduly restrict withdrawals (section 6.4). A preliminary study (section 6.5) of the no-net-loss of median monthly habitat criterion showed the criterion also severely restricted water withdrawals. Therefore, procedures were developed to estimate the impact of withdrawals and passby flows over the range of flows in different seasons.

The impact analysis procedures for water withdrawals provide information necessary to make decisions regarding:

- The magnitude of the impact associated with various combinations of withdrawal and passby flow;
- The passby requirement for a proposed withdrawal at a specified location; and
- The percent of time that withdrawals cannot be made because of passby requirements.

6.2 Definition of Median Monthly Habitat

The median monthly habitat can be defined as the median of all daily habitat values for a given month, or as the habitat available at the median monthly flow. Since the relationship between habitat and flow rate is generally nonlinear, it was expected these two definitions would produce different values of the median monthly habitat.

For the first definition, the median monthly habitat has to be derived from a statistical analysis of all the daily habitat values occurring in a given month at each study site. This method of computation requires:

- Estimation of daily flows at every study site;
- Computation of daily habitat values from the daily flows and the flow versus habitat table developed from the HABTAE analysis; and
- Statistical analysis of the daily habitat values to determine the median monthly habitat value.

Considering the amount of work involved in this analysis, and the concern that the two different definitions would produce different values, a pilot study was performed to compare the median monthly habitat for all species and life stages being analyzed, using both methods. The pilot study was performed at the same study sites used in the pilot study described in section 5.8.3.

In all cases, the median monthly habitat computed from the median monthly flow was within 2 percent of the value computed by statistical analysis of the daily habitat time series. Since the results were the same for all 12 sites, the median monthly habitat was defined as the habitat value associated with the median monthly flow in subsequent analyses.

6.3 WUA for Combinations of Life Stages

Analysis of habitat versus flow relationships for multiple fish species and multiple life stages is complex, because of different habitat preferences for different life stages, and the presence or absence of different life stages at particular times of year. The spawning and fry life stages of the study species prefer habitat with low depths and velocities, while adults and juveniles prefer higher depths and velocities. Since the different life stages have different habitat requirements, changes in flow that reduce habitat for one life stage may increase habitat for another life stage. Based on the periodicity chart (Table 3.4), the adult and juvenile life stages are present all year long, but the spawning and fry life stages are present only for about 5 months and 4 months, respectively.

One approach to analyzing habitat for multiple species and life stages is to combine the individual WUA curves for each life stage into a single curve that represents the WUA versus flow relationship for all life stages of a given species, and to use that curve to evaluate changes in WUA resulting from withdrawals. One such method for combining life stages is the maximum of the minimum habitat values at_each discharge, as described by Orth and Leonard (1990). This method assumes the life stage with the lowest WUA at a given flow, relative to the maximum habitat for all life stages present at that time of year, is the most habitat-limited, and therefore the most critical life stage to be protected.

Different life stages are present at different times of year (Table 3.4), so combined WUA tables are needed for each possible combination of life stages, i.e., adult/juvenile/fry, adult/juvenile/spawning, and adult/juvenile. A sample computation of the combined WUA curves is shown in Table 6.1

The first step in combining the WUA relationships is to tabulate the WUA data for each life stage and each simulation flow, as shown in the columns headed Weighted Usable Area. Typically, the WUA has different magnitude for different life stages for a given flow. Also, the WUA data show different trends for different life stages. In this example, the WUA for the adult and juvenile life stages increases with increasing flow over the entire range of simulation flows. However, WUA for the spawning life stage has a maximum at a simulation flow of 4.91 cfs, and for the fry life stage, the WUA peaks at a simulation flow of 0.76 cfs.

The second step is to put all the WUA data on a comparable scale, by dividing the WUA for each life stage by the maximum value, shown at the bottom of the table, for that life stage. This results in rescaling all the data to the range from zero to unity, as shown in the columns headed Normalized Weighted Usable Area.

Table 6.1 Example Computation of Combined Habitat, Green Creek, Segment 1, Brook Trout

Drainage area at site: 2.6 square miles
Average daily flow: 4.4 cfs
Annual median flow: 2.5 cfs

Simulated Flow (cfs)	Weighted Usable Area (square feet per thousand feet of stream)				Normalized Weighted Usable Area			
	Adult	Juvenile	Spawning	Fry	Adult	Juvenile	Spawning	Fry
0.42	664.72	1,766.67	1,001.39	1,726.70	0.359	0.472	0.571	0.990
0.53	721.55	1,878.57	1,066.90	1,710.23	0.390	0.502	0.608	0.981
0.65	796.02	2,031.52	1,155.62	1,723.81	0.430	0.543	0.659	0.989
0.76	849.33	2,158.53	1,236.56	1,743.60	0.459	0.577	0.705	1.000
0.86	892.00	2,234.56	1,290.77	1,716.47	0.482	0.597	0.736	0.984
0.97	939.83	2,318.00	1,328.13	1,683.01	0.508	0.619	0.757	0.965
1.07	990.77	2,428.81	1,379.91	1,685.53	0.536	0.649	0.786	0.967
1.18	1,018.35	2,496.07	1,412.77	1,662.13	0.551	0.667	0.805	0.953
1.28	1,060.61	2,578.90	1,450.34	1,637.70	0.574	0.689	0.827	0.939
1.80	1,205.83	2,909.19	1,551.68	1,553.12	0.652	0.777	0.884	0.891
2.32	1,336.82	3,175.69	1,635.44	1,511.73	0.723	0.849	0.932	0.867
2.84	1,433.29	3,356.81	1,672.94	1,392.18	0.775	0.897	0.953	0.798
3.10	1,456.89	3,400.47	1,676.07	1,360.04	0.788	0.909	0.955	0.780
3.37	1,505.50	3,484.10	1,692.68	1,329.86	0.814	0.931	0.965	0.763
3.63	1,536.59	3,547.27	1,706.22	1,302.04	0.831	0.948	0.972	0.747
4.91	1,656.49	3,640.53	1,754.76	1,234.77	0.896	0.973	1.000	0.708
6.18	1,740.94	3,680.77	1,693.78	1,203.68	0.942	0.984	0.965	0.690
7.42	1,849.11	3,742.42	1,643.97	1,143.86	1.000	1.000	0.937	0.656
Maximum	**1,849.11**	**3,742.42**	**1,754.76**	**1,743.60**				

Table 6.1. Example Computation of Combined Habitat, Green Creek, Segment 1, Brook Trout —Continued

Simulated	Minimum Normalized Weighted Usable Area			Flow			Renormalized Minimum Weighted Usable Area		
Flow (cfs)	Adult/Juvenile/ Fry	Adult/Juvenile/ Spawning	Adult/ Juvenile	csm	% average daily flow	% annual median	Adult/Juvenile/ Fry	Adult/Juvenile/ Spawning	Adult/ Juvenile
0.42	0.359	0.359	0.359	0.165	9.46	16.67	0.461	0.382	0.359
0.53	0.390	0.390	0.390	0.208	11.94	21.03	0.500	0.414	0.390
0.65	0.430	0.430	0.430	0.255	14.64	25.79	0.552	0.457	0.430
0.76	0.459	0.459	0.459	0.298	17.12	30.16	0.589	0.488	0.459
0.86	0.482	0.482	0.482	0.337	19.37	34.13	0.618	0.512	0.482
0.97	0.508	0.508	0.508	0.380	21.85	38.49	0.652	0.540	0.508
1.07	0.536	0.536	0.536	0.420	24.10	42.46	0.687	0.569	0.536
1.18	0.551	0.551	0.551	0.463	26.58	46.83	0.706	0.585	0.551
1.28	0.574	0.574	0.574	0.502	28.83	50.79	0.735	0.609	0.574
1.80	0.652	0.652	0.652	0.706	40.54	71.43	0.836	0.693	0.652
2.32	0.723	0.723	0.723	0.910	52.25	92.06	0.927	0.768	0.723
2.84	0.775	0.775	0.775	1.114	63.96	112.70	0.994	0.823	0.775
3.10	0.780	0.788	0.788	1.216	69.82	123.02	1.000	0.837	0.788
3.37	0.763	0.814	0.814	1.322	75.90	133.73	0.978	0.865	0.814
3.63	0.747	0.831	0.831	1.424	81.76	144.05	0.957	0.883	0.831
4.91	0.708	0.896	0.896	1.925	110.59	194.84	0.908	0.951	0.896
6.18	0.690	0.942	0.942	2.424	139.19	245.24	0.885	1.000	0.942
7.42	0.656	0.937	1.000	2.910	167.12	294.44	0.841	0.995	1.000
Maximum	**0.780**	**0.942**	**1.000**						

Next, for each combination of life stages, compare the normalized WUA for each simulation flow, across those life stages, and determine the minimum value. Tabulate these minimums, as shown in the columns headed Minimum Normalized Weighted Usable Area, for the appropriate combination of life stages. For the first combination of life stages (adult/juvenile/fry) shown in the example, the normalized WUA for the adult life stage is less than the normalized WUA for the juvenile life stage over the entire range of flows. However, the normalized WUA for the adult life stage is less than the normalized WUA for the fry life stage over the simulation flow range less than 3.1 cfs. Therefore, in this example, the adult life stage is the most limited up to a simulation flow of 3.1 cfs, and the fry life stage is the most limited for greater flows. The minimum normalized WUA values are equal to the normalized adult values over the range of simulation flows less than 3.1 cfs, and are equal to the nomalized fry values for higher flows. A similar process is used to compute minimum normalized WUA for the combined adult, juvenile, and spawning life stages, and for combined adult and juvenile life stages, with the results shown in the corresponding columns of the table.

The next step is to renormalize the minimum normalized WUA values to span the range from zero to unity. First find the maximum value for each combination of life stages (column), and tabulate as shown at the bottom of the column. Then divide the minimum normalized WUA in each column by the maximum value in the column, and tabulate as shown in the last three columns of the table. The result is called the RMWUA. Finally, the simulated flows are converted to unit values (csm), percent ADF, and percent annual median flow, as shown in the columns headed Flow.

The computation of the combined life stages were made for brook trout, brown trout, and combined brook trout and brown trout at each of the 97 study sites.

6.4 Habitat Loss Criteria

Two definitions of habitat loss were considered, no-loss of habitat, and no-net-loss of median monthly habitat. For this study, no-loss of habitat was defined as no reduction in WUA, using the appropriate relationships for WUA versus flow. No-net-loss of habitat was defined as no reduction of WUA at the median monthly flow. A given quantity of habitat was assumed to have the same value for every life stage.

The WUA versus flow relationships have different shapes, as illustrated in Figure 6.1. These curves can be classified as follows:

- Class 1: WUA always increasing with increasing flows;
- Class 2: WUA always decreasing with increasing flows;
- Class 3: WUA rising and then declining; and
- Class 4: Constant WUA with increasing flow.

The difference between no-loss and no-net-loss criteria depends on the type of curve. For class 2 and class 4, there are no differences between the two types of criteria. For the other two classes, the difference between habitat loss criteria depends on the relative magnitude of the flow corresponding to the peak of the curve (Q_p), the median monthly flow (Q_M), and the flow actually occurring at any given time (Q_A). Four different combinations of Q_p, Q_M, and Q_A, and the amount of flow that can be withdrawn for each criterion for each case are shown in Figure 6.2. (Some combinations are not shown.)

The no-loss of habitat criterion allows withdrawals at a given flow only if the amount of habitat increases or remains the same with decreased flow. The no-net-loss of median monthly habitat criterion allows withdrawals if the habitat does not decline below that which is present at the median monthly flow.

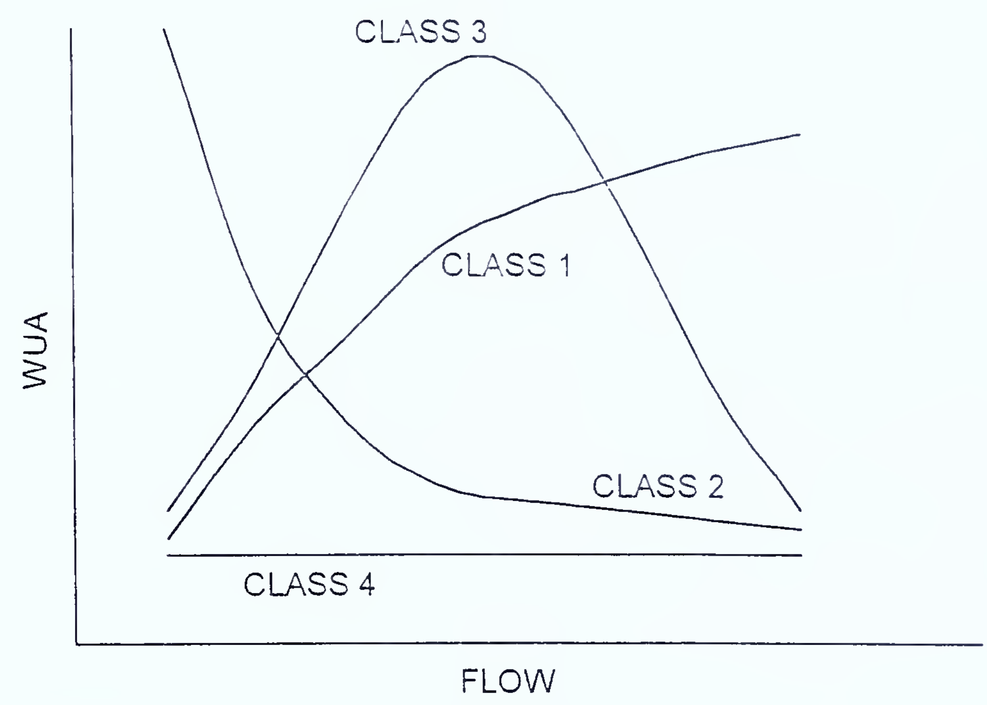

Figure 6.1. Typical Shapes of Weighted Usable Area Versus Flow Relationships

If the actual flow and the median monthly flow both exceed the flow at the peak of the WUA curve (Figure 6.2, cases 3A and 3B), the no-loss of habitat criterion allows withdrawals to the flow less than Q_P, which has the same habitat as the actual flow; the no-net-loss-of median monthly habitat criterion allows withdrawals to the flow less than Q_P, which has the same amount of habitat as the median monthly flow. If the actual flow and the median monthly flow are both less than the flow at the peak of the WUA curve (Figure 6.2, cases 3C and 3D), the no-loss of habitat criterion allows no withdrawal, but the no-net-loss of median monthly habitat criterion allows withdrawals to the median monthly flow. Thus, the no-loss criterion restricts withdrawals at higher flows than the no-net-loss of median monthly habitat in cases 3A and 3C, and allows withdrawals to a lower flow only in case 3B.

The no-net-loss of habitat criterion was used because the median monthly habitat is considered the appropriate measure of the amount of habitat typically available. The no-net-loss criterion was further examined, as discussed in section 6.5. The no-loss criterion was not used because it unnecessarily limits the withdrawals under a wide range of conditions, considering that natural flow and available habitat fluctuate within months, and years, and among years.

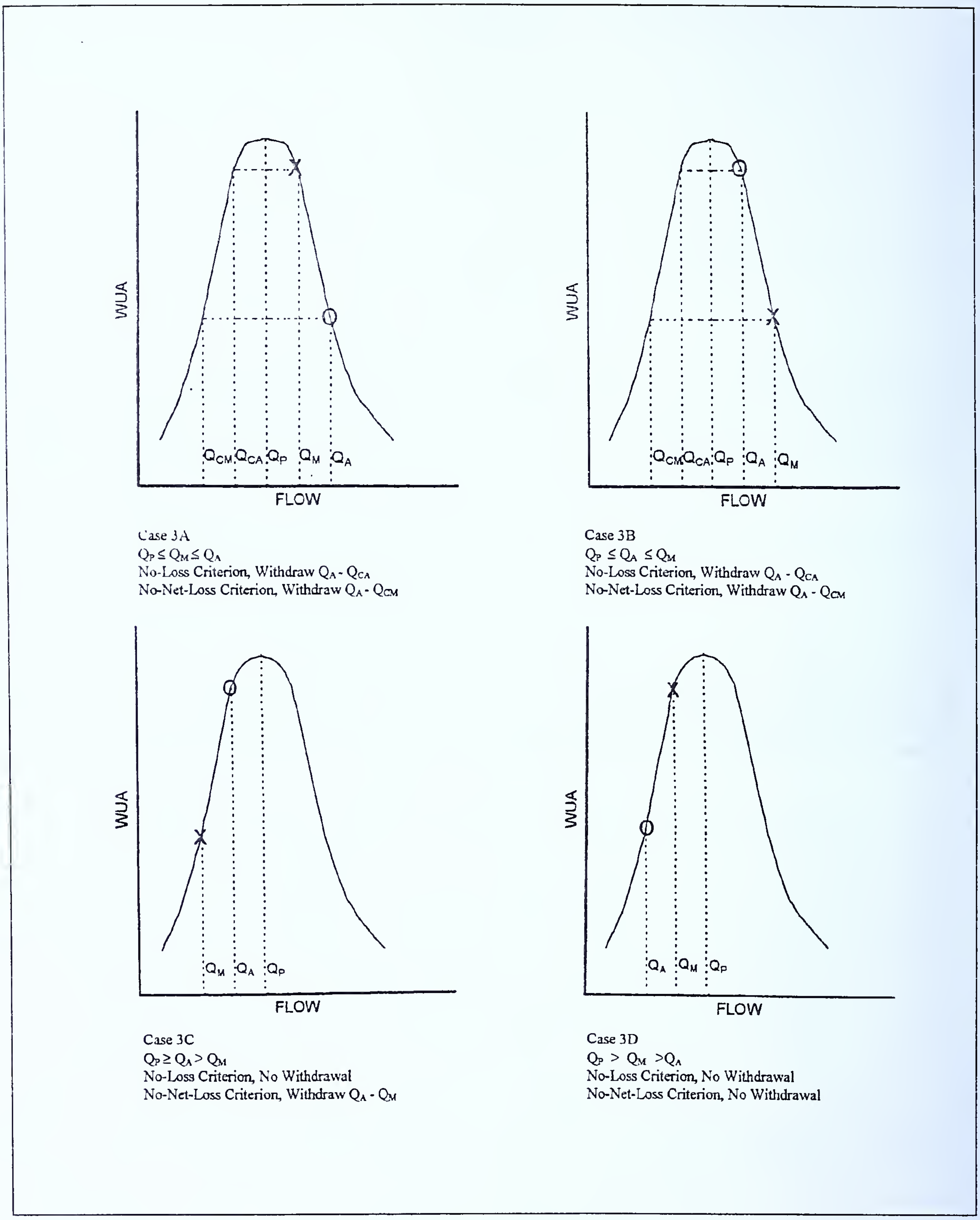

Figure 6.2. Illustration of Effects of Different Habitat Loss Criteria on Withdrawals for Different Flow Relationships

6.5 Evaluation of No-Net-Loss Criterion

Utilizing the procedure for combining habitat values for different life stages (section 6.3), the no-net-loss flow is equal to the smaller of the median monthly flow, or, if the median monthly flow exceeds the flow at the peak of the RMWUA curve, the flow less than the peak at the same RMWUA.

The no-net-loss flow was computed for brook and brown trout, for the summer season (adult and juvenile life stages), for 11 randomly-selected study sites. The flow corresponding to the maximum RMWUA was tabulated for each month. This peak RMWUA flow was then compared to the median monthly flow at the study site to determine the no-net-loss flow. The results of this analysis are summarized in Table 6.2.

In the 66 situations that were analyzed (11 streams x 3 months x 2 species), the no-net-loss flow was equivalent to the median monthly flow, except for brook trout for Monocacy Creek Segment 3. For that stream, the no-net-loss flow could not be determined, because the lowest flow simulated was not low enough to allow interpolation for the habitat at a flow less than the flow at the maximum RMWUA (Q_{CM} in Figure 6.2, case 3B).

This test of the no-net-loss of habitat criterion showed the peak RMWUA flow was greater than the median monthly flow for the summer months, for most streams (Figure 6.2, case 3D). That result implies the ability to withdraw water would be severely limited for that season.

This initial application of the no-net-loss of habitat procedure suggested more detailed procedures were needed to assess the impact of water withdrawals. These procedures will be described in sections 6.6.2 and 6.6.4.

6.6 Impact Analysis

6.6.1 Impact analysis concepts

The purpose of the impact analysis is to determine the magnitude of impact of withdrawals and passby flows on habitat, over the full range of flows and passbys, and to use that information to establish criteria for passby flows. Passby flow is defined as the flow rate below which no water withdrawal may be taken. The impact is defined as the percentage difference between habitat available without the withdrawal and habitat available with the withdrawal and passby in place. A percent reduction in habitat can be compared to an acceptable level.

As described previously, RMWUA versus flow relationships have been developed for study sites on study streams randomly selected to be representative of all the streams within each segment class of streams evaluated in each study area. Reproducing trout streams were classified by study region and segment number.

For each study stream, RMWUA represents a measure of the habitat available at a given flow relative to the peak habitat available over the entire range of possible flows on that stream. It can be used to compare relative habitat values between streams that may vary significantly, in terms of absolute size or absolute amount of habitat. For that reason, it was used as the measure of habitat in the impact analyses.

Table 6.2. Comparison of Median Monthly Flows, No-Net-Loss Flows, and Flow at Maximum Renormalized Minimum Weighted Usable Area for Adult/Juvenile Brook Trout

Stream Name	Flow at Peak of A/J RMWUA Curve	July		August		September	
		Median Monthly Flow	No-Net-Loss Flow	Median Monthly Flow	No-Net-Loss Flow	Median Monthly Flow	No-Net-Loss Flow
	cfs						
R&V Limestone							
Bushkill Creek–Seg. 2	152.4	48.1	48.1	46.3	46.3	41.3	41.3
Cedar Run (Cumb)	9.6	4.6	4.6	4.2	4.2	3.2	3.2
Monocacy Creek–Seg. 3	20.8	31.8	—	30.3	—	26.9	—
Spring Creek (Centre)–Seg. 1	44.6	17.8	17.8	15.1	15.1	14.2	14.2
R&V Freestone							
Fowler Hollow Run–Seg. 2	6.8	1.7	1.7	1.2	1.2	1.0	1.0
Green Creek–Seg. 3	43.9	14.8	14.8	11.2	11.2	9.8	9.8
Mile Run	4.4	0.9	0.9	0.6	0.6	0.6	0.6
Unglaciated Plateau							
Bloomster Hollow	1.8	0.7	0.7	0.5	0.5	0.5	0.5
Cherry Run	10.7	1.8	1.8	1.3	1.3	1.1	1.1
Fall Creek–Seg. 2	24.1	2.5	2.5	2.0	2.0	1.6	1.6
E. Br. Spring Creek	36.1	33.0	33.0	24.0	24.0	21.0	21.0

Impact analysis can be performed using either flow and habitat time series or flow and habitat duration analysis to evaluate effects of the withdrawal on the available habitat (Bovee, 1982). A time series is simply a record of any variable of interest such as flow or habitat in chronological order. Duration analysis generally involves ranking the appropriate variable (e.g., flow or habitat) in order of magnitude, and then determining the probability of exceedance of that variable. Habitat duration can be determined either by ranking habitat values for probability analysis, or by converting ranked flow values to habitat and assigning the probability of the flow values to the habitat values. The latter method will be called associated habitat duration analysis in this report. Because the habitat available at any time is related to the flow value at that time, the probability of that flow also is the probability of the associated habitat. Both methods of evaluating impact are described in the following sections.

The impact analyses are performed on a monthly, seasonal, or annual basis. Seasons are defined by changes in trout life stage combinations during the year, as shown in the periodicity chart (Table 3.4). Thus, spring (adult, juvenile, and fry life stages) is defined as March, April, May, and June; summer (adult and juvenile life stages) is defined as July, August, and September; and fall/winter (adult, juvenile, and spawning/incubation life stages) is defined as October, November, December, January, and February.

6.6.2 Flow and habitat time series impact analysis

6.6.2.1 General discussion

The following method was developed to utilize the RMWUA versus flow relationships for the study streams to estimate the impact of withdrawals and passby flows on habitat for any other stream in the same class of streams, for which a withdrawal is proposed. Streams from which withdrawals are proposed will be called "project streams."

Time series analysis of flows can use any time step such as the flow recorded every hour, or median or average flows during each month or year. This method uses a monthly time step and median monthly flows. A monthly time step represents a reasonable level of effort from an analytical and practical standpoint, and median flows are typically considered the best measure of central tendency in flow analyses.

The first step in this method is to develop ADF and time series of median monthly flows for a selected period of record for the project stream. These flows should be derived from the flow records at a nearby stream gage. A method for developing median monthly flows for ungaged locations within the Ridge and Valley Freestone, Ridge and Valley Limestone, and Unglaciated Plateau study regions is described in section 6.6.3.

Once the median monthly flow time series has been determined, a set of RMWUA time series is developed, using the RMWUA versus flow relationships (section 6.3) for each of the study streams in a class. The time series of median monthly habitat for the project stream is developed by averaging the median monthly habitat values for the study streams in the appropriate segment class.

Although the programs were developed using median monthly flows, other flow statistics and/or time steps can also be used. For example, minimum monthly flow time series, or up to 2.5 years of daily flow time series can be evaluated.

Two closely-related computer programs were written in Microsoft Excel 7.0 spreadsheet format to estimate impacts of withdrawals. The first program, called the "detailed analysis

program," estimates the effect of any combination of withdrawal and passby flow on the flow and habitat of a project stream, and presents these effects in several different ways. The second program, called the "preliminary analysis program," was designed to provide general estimates of impacts from a proposed withdrawal, while reducing the run time necessary to analyze the same number of passby flows with the detailed analysis program. The outputs from the preliminary analysis program are less detailed than those of the detailed analysis program. The two programs are described and compared further in the following sections.

The detailed and preliminary analysis programs can be used for the Unglaciated Appalachian Plateau, the Ridge and Valley Limestone, and the Ridge and Valley Freestone study regions. The programs cannot be used for the Piedmont Upland region because field data has been collected for only 12 of the 30 segments considered necessary to provide an appropriate level of accuracy for this region. The RMWUA versus flow data for these 12 sites have been entered into the program.

For the regions that have been completed, both programs can analyze the following cases: wild brook, brown, or combined trout; stocked adult brook, brown, or combined trout; and stocked fingerling brook, brown, or combined trout. The main difference between wild, stocked adult, and stocked fingerling cases is that different life stages are used in the various habitat analyses. For wild trout, all life stages present in a given season are included in the analyses. For stocked adult trout, only the adult life stage is considered for the entire year. For stocked fingerling trout, only the adult and juvenile life stages are included for all seasons.

The time series analysis programs, at present, address only diversions of water from a stream. The program does not address changes in natural flows caused by releases from instream reservoirs, at this time. A reservoir operations model would have to be linked to this program to make such analyses possible. It is recommended this be the next step in development of the computer program.

Detailed descriptions of computations and procedures for use of detailed and preliminary analysis programs are given in Appendix E.

6.6.2.2 The detailed analysis program

The ADF and a table of median monthly flows for each year in the available flow record is developed for the project stream, using the regional hydrology method discussed in section 6.6.3. These flows are expected to occur on the stream under existing conditions, unimpacted by the proposed withdrawal. The program converts the flow values to percent ADF to make comparisons of flow and habitat among streams possible. Then the unimpacted flows from the project stream are used to develop time series of unimpacted habitat for each study stream by using the flow time series for the project stream and RMWUA versus flow relationships for each study stream.

The proposed withdrawal from the project stream and a proposed passby flow are then entered into the Excel program. Both the withdrawals and the passby flows can vary seasonally. The unimpacted flow time series is adjusted by the program to produce a time series of impacted flows, and corresponding tables of habitat are developed for the study streams. The flow and habitat available for unimpacted and impacted conditions are compared to determine the absolute and percentage change in flow and habitat.

After the tables of monthly unimpacted and impacted RMWUA values have been developed, the corresponding monthly habitat values from the tables are averaged for each condition. Because the use of RMWUA as the measure of habitat allows comparison of habitat available across different streams, habitat versus flow relationships for each study stream are weighted equally to

develop average habitat estimates for a class of streams. Summary statistics such as average monthly, seasonal, or annual RMWUA and flow values are calculated from the tables for each condition, and confidence intervals (95 percent) for the summary statistics derived. In addition to these measures of flow and habitat, the program develops duration analyses of both median monthly flow and RMWUA for both the unimpacted and impacted conditions. These analyses are presented in both tabular and graphical form. The summary statistics and the duration analyses are compared to determine the impact of the withdrawal. These comparisons can be made on a monthly, seasonal, or annual basis.

The computer program is described in more detail in Appendix E.

6.6.2.3 The preliminary analysis program

The preliminary analysis program also uses the median monthly flow time series for the study site, but it does not require the entry of passby flows. During each run, it automatically computes the habitat values that result from a range of possible passby flows between 0 and 60 percent ADF, at 5 percent increments. The passby flows are held constant throughout the year, rather than varying seasonally, as in the detailed analysis program. Impacts are expressed in terms of percent change in average seasonal and average annual RMWUA, and absolute and percentage change in median seasonal and median annual RMWUA.

The output from the preliminary analysis program does not provide any comparisons of flow, monthly RMWUA, confidence intervals, or duration analyses, as does the detailed analysis program.

Also, the preliminary analysis program uses a different algorithm than the detailed analysis program to estimate impacts to seasonal average and median RMWUA. The differences are explained in Appendix E. Consequently, the results will be similar, but probably not identical, for the two programs.

The results of the preliminary analysis program are simply meant as a general overview of impacts, and can serve as a starting point for more complete analyses using the detailed analysis program.

6.6.2.4 Habitat impact curves: development

The detailed analysis program has been used to develop sets of habitat impact curves for the Unglaciated Plateau, Ridge and Valley Freestone and Ridge and Valley Limestone study regions.

The detailed analysis program computes impact of a given withdrawal and passby for each median monthly flow value for the period of record, and calculates various measures of habitat impact, including maximum, average annual, and 90 percent probability of exceedance. The relationships between these three measures of impact are shown in Figure 6.3. The median monthly flow duration plots, with and without the withdrawal, are illustrated in Figure 6.3A. Note that the maximum impact in percent flow reduction occurs when the natural flow is equal to the sum of the passby flow plus the withdrawal. At this flow level, the reduction in habitat also is the greatest. As natural flows decrease from the maximum impact flow, withdrawals are reduced to maintain the passby flow. When flows become less than the passby flow, no withdrawals may be made; therefore, no impacts to flow or habitat occur at flows less than the passby flow. For natural flows greater than the flow at maximum impact, the impacts to habitat generally decrease, until at some higher flow, the withdrawals produce

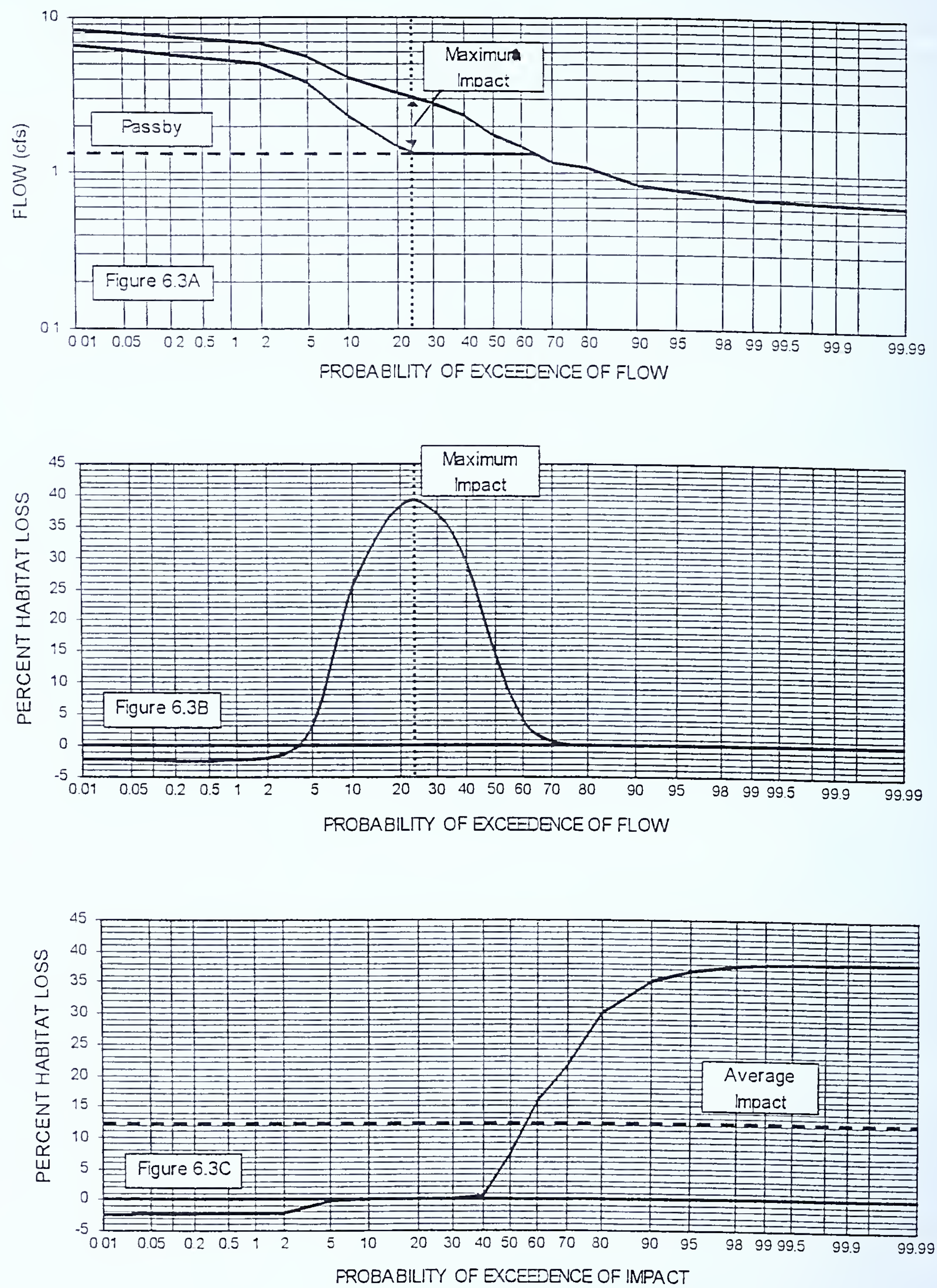

Figure 6.3. Illustrations of Impact on Flow and Habitat at Green Creek, Ridge and Valley Freestone Region (NOTE: Results depict impacts for a 40 percent withdrawal and a 30 percent passby.)

depths and velocities that improve fish habitat. These habitat impacts are illustrated as a percent loss in habitat on the same probability scale in Figure 6.3B. Habitat gains are shown as negative habitat losses.

If all of the habitat impacts in Figure 6.3B are ranked from highest to lowest, the habitat impact duration curve will have the general shape shown in Figure 6.3C. The maximum impact always occurs at the 100 percent probability level, but also may occur at lower probabilities. In the example, the maximum impact (38 percent reduction) occurs over the range from 98 to 100 percent probability. The 90 percent impact is the impact that is exceeded 90 percent of the time (35 percent habitat reduction). The average impact is simply the algebraic average of all the individual values.

The purpose of instream flow protection is to protect fish populations against significant short-term and long-term impacts of a withdrawal. The various impact values between average and 100 percent probability of exceedance could be used to evaluate the full range of withdrawals and passby combinations. The average impact value gives a measure of the long-term impact of the withdrawal, while the maximum impact measure defines the worst possible impact in a short-term period. In the absence of a passby flow, the maximum impact measure defines the fishery impacts in the worst year of record. For withdrawals less than the lowest flow on record, the maximum impact generally occurs very infrequently. As withdrawals increase, passby flows become essential as the withdrawal approaches the record low flow. When the withdrawal equals or exceeds the record low flow, the impact approaches 100 percent, and may occur fairly frequently depending on the magnitude of the withdrawal. Such a large impact is considered unacceptable. Passby flow protection is required before that occurs, and low flows are fully protected at both the median and daily low flow levels. The introduction of a passby flow reduces the maximum impact substantially and shifts its probability of occurrence to a more frequent flow level.

Three measures of impact were examined more closely, the maximum, average, and the 90 percent probability of exceedance. The average impacts were felt to be useful because they showed the long-term impacts to the fishery habitat, provided there is sufficient passby flow protection to guard against severe short-term habitat losses. The maximum impact curves likewise are important because they depict the worst possible short-term impacts.

In considering maximum habitat impacts, the fact that median monthly flows were used becomes a concern, since 50 percent of the flow values in a month are less than the median. The flow duration curves for median monthly flows and daily flows are almost identical between the 5 percent and 95 percent exceedance levels. Therefore, the concern for maximum impacts will be eliminated if the passby flow is selected to protect median monthly flows at approximately the 95 percent probability of exceedance level, as shown in Figure 6.3A. Flows greater than 5 percent probability can be considered flood flows, and flows less than 95 percent probability can be considered drought flows.

The detailed analysis program was run repeatedly for 27 combinations of withdrawal and passby flows (e.g., 10 percent ADF withdrawal and 5 percent ADF passby). The average annual impacts were determined for each representative stream gage in the region. The maximum, minimum, and average values across streams were tabulated. For example, in the Ridge and Valley Freestone region, six gages were used to represent the hydrology of the 21 segment class 1 sites. Therefore, six streams were chosen to represent the six contributing gages, and the withdrawal/passby combinations were run for only those six streams, rather than all 21. The study streams used in the impact analysis are shown in Table 6.3. The model was run using the hydrology for each of the six streams. The average annual impacts from the six representative streams were averaged and tabulated along with the maximum and minimum values of the average impacts across the six representative streams.

Table 6.3. Study Streams Used in Habitat Impact Analysis

Region	Gage	Representative Study Stream	Segment 1	Segment 2	Segment 3	Segment 4
Ridge and Valley Limestone Group 1	Letort Spring Run near Carlisle	Letort Spring Run	X	X		
	Spring Creek at Houserville	Spring Creek	X	X	X	X
		Penns Creek	X	X	X	
	Yellow Breeches Cr. near Camp Hill	Cedar Creek, Cumberland Co.	X			
Ridge and Valley Limestone Group 2	Bixler Run near Loysville	Long Hollow Run	X			
	Kishacoquillas Creek at Reedsville	Honey Creek	X			
	Monocacy Creek at Bethlehem	Monocacy Creek	X	X	X	X
		Bushkill Creek		X		
Ridge and Valley Freestone	Wapwallopen Cr. near Wapwallopen	Wapwallopen Creek	X	X	X	X
		Mugser Run		X		
	Fishing Creek near Bloomsburg	Green Creek	X	X	X	
	Sherman Creek at Shermans Dale	Big Run	X			
		Fowler Hollow		X		
	Sand Spring Run near White Deer	Sand Spring Run	X			
		Rapid Run		X	X	
	Bald Eagle Creek at Tyrone	Big Fill Run	X	X		
	Aughwick Creek near Three Springs	Laurel Run, Huntingdon Co.	X			
Unglaciated Plateau	W. Branch Susquehanna R. at Bower	Dunlap Run	X			
		Cush Creek		X		
	Laurel Hill Creek at Ursina	Whites Creek	X	X		
		Falls Creek		X		
	Mahoning Creek at Punxsutawney	Beech Run	X			
	S. Fork Beech Creek near Snow Shoe	Benner Run	X			
	Oil Creek at Rouseville	Lower Two Mile Run	X	X		
	Potato Creek at Smethport	Strange Hollow	X			
	Blacklick Creek at Josephine	Findley Run	X			
	W. Branch Clarion River at Wilcox	Cherry Run	X			
		E. Branch Spring Creek Segment 2		X		
	Driftwood Branch Sinnemahoning Creek at Sterling Run	Tannery Hollow	X			

The mean impact percentages, for each combination of withdrawal, and passby flow, were used to plot curves of constant impact such as a curve where there is a constant habitat loss of 25 percent. These curves of constant habitat impacts were developed for each segment in all three study regions, and have been developed for the average annual impact measure for all three study regions, and for the maximum impact measure for the Ridge and Valley Freestone study region.

6.6.2.5 Habitat impact curves: results and discussion

Ten different constant impact curves based on the average impact measure are shown in Figure 6.4 through 6.13. All life stages present in a given season were used in this analysis so these curves apply only to the wild trout cases (section 6.6.2.1). There are two curves for the Ridge and Valley Freestone study region, four for the Ridge and Valley Limestone study region, and four for the Unglaciated Plateau study region. In these graphs, for a constant level of withdrawal, the impact increases from right to left.

For the Ridge and Valley Freestone study region, the curves for segment classes 1, 2 and 3, for each level of impact, were close to each other. For a given level of impact, the range of passby flows for different segments was always within about +/- 4 percent ADF. Therefore, those curves were averaged, and the average curve for each level of impact is shown in Figures 6.3 and 6.4. The constant impact curve for segment class 4 sites plots to the left of the corresponding curves for segments 1 through 3. However, the segment class 4 curve is based on only 1 site, Wapwallopen Creek (Table 6.3). Because of the small number of study sites, the constant habitat impact curves for segment class 4 sites are not shown.

Habitat impact plots for all the Ridge and Valley Limestone study streams showed significant scatter for different study streams. For withdrawals less than about 20 percent ADF, streams with more than 50 percent limestone showed little or no change in impact to RMWUA with increasing passby flows. Streams with less than 50 percent limestone showed decreasing percentage reductions in habitat with increasing passby flow over essentially the entire range of passby flows and withdrawals. Therefore, each representative study site was classified according to whether the part of the watershed underlain by limestone is greater or less than 50 percent. In the first case, the base flows are relatively high, and the withdrawal has little impact up to about 20 percent ADF withdrawal, and passby flows have little effect within that range. For the second case, the base flows are relatively low, so that low levels of withdrawal cause impacts on habitat for those study sites.

For study sites included in the first group, the constant habitat impact curves for segment class 2 and 3 sites are much higher (shifted to the left) than either the segment class 1 or 4 curves. The constant impact curves for sites included in the second group showed similar, but less extreme, behavior. This erratic behavior is believed to be due to a combination of hydrology and small sample size for segment class 2, 3, and 4 study sites. Several of these streams have higher flows per unit area or as a percentage of ADF in segment 2 or segment 3 compared to segment 1, because of springs, underflow, or WWTP return flows. As shown in Table 6.3, there are only a few segment class 2 and segment class 3 sites in each subregion included in the impact analysis, and there is only one segment class 4 site (Spring Creek, Centre County). Also, the Honey Creek study site is classified as segment class 1 because it is a short distance downstream from the upstream limit of the limestone rock. However, it is probably not a typical segment class 1 site, because there is a large watershed (about 90 square miles) upstream of the site, most of which is underlain by freestone.

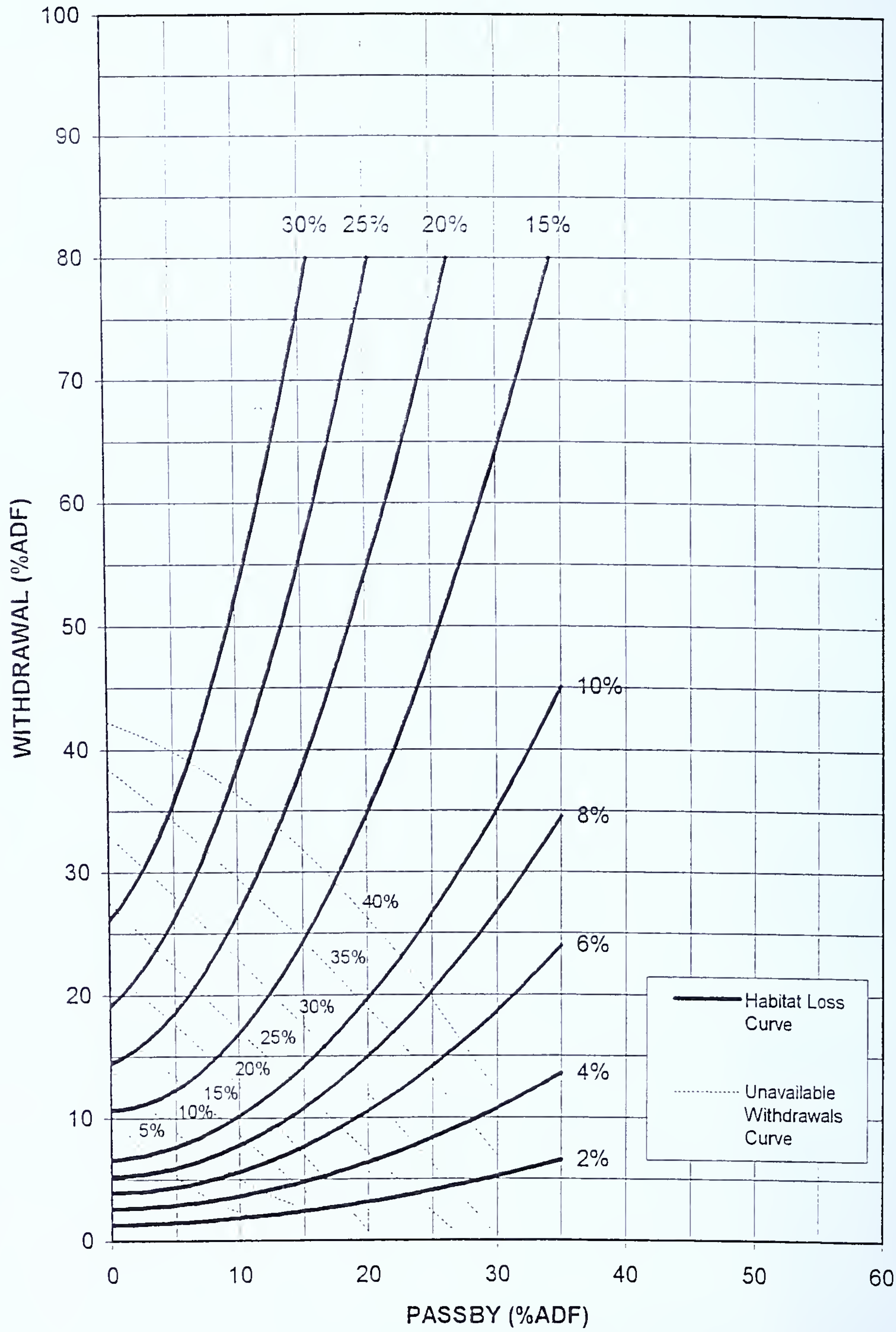

Figure 6.4. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brown and Combined Species

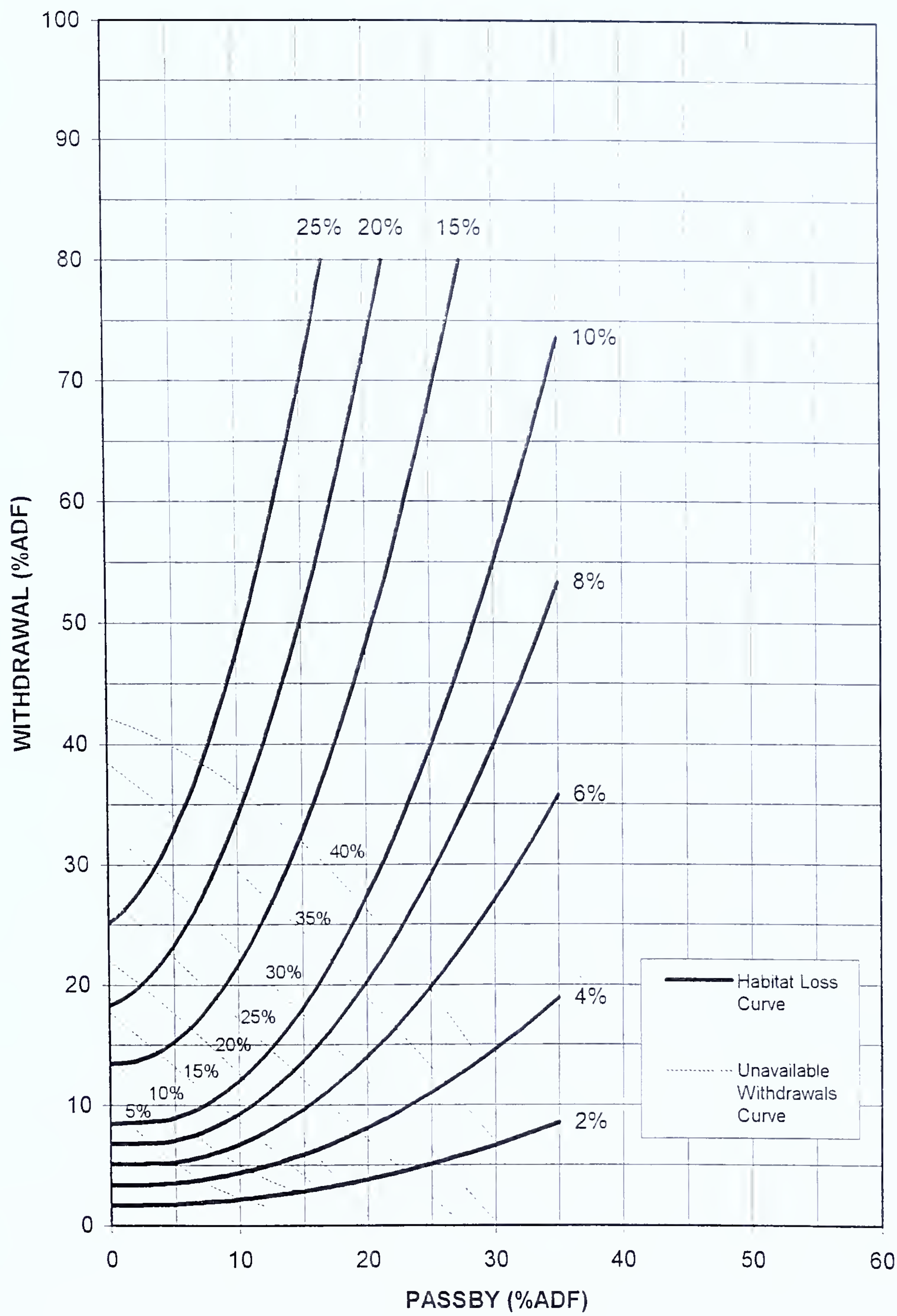

Figure 6.5. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brook Trout

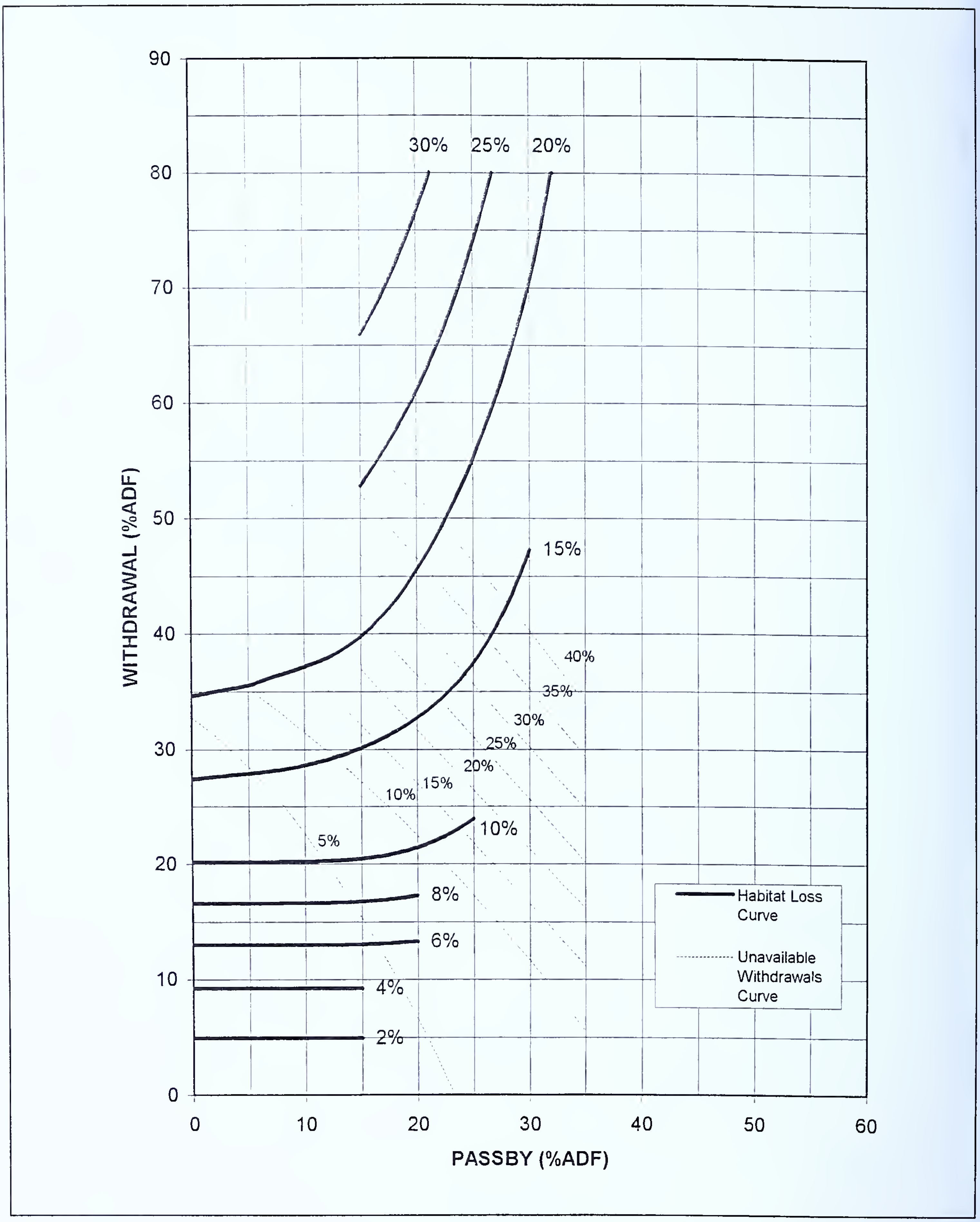

Figure 6.6. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brown and Combined Species

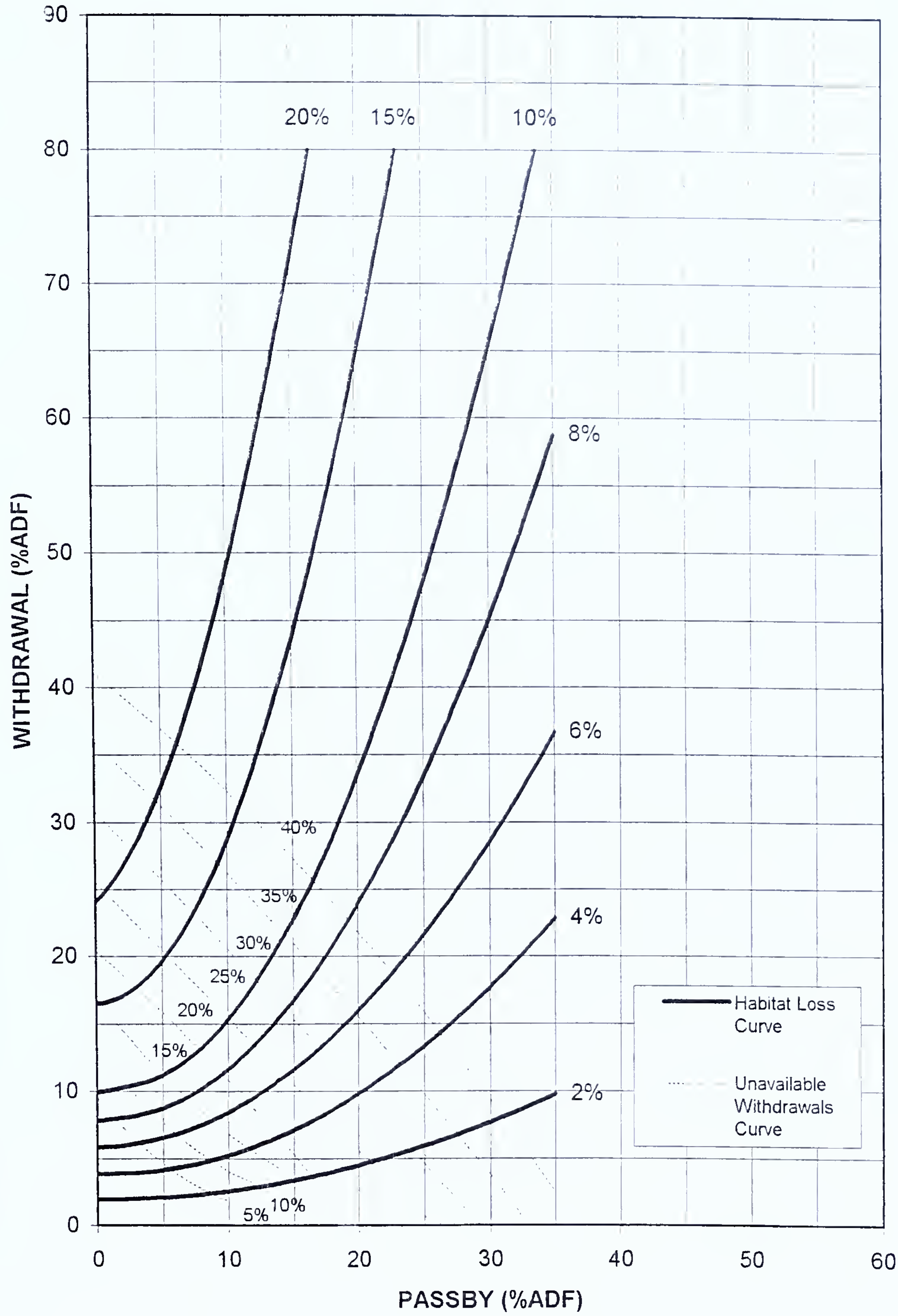

Figure 6.7. *Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brown and Combined Species*

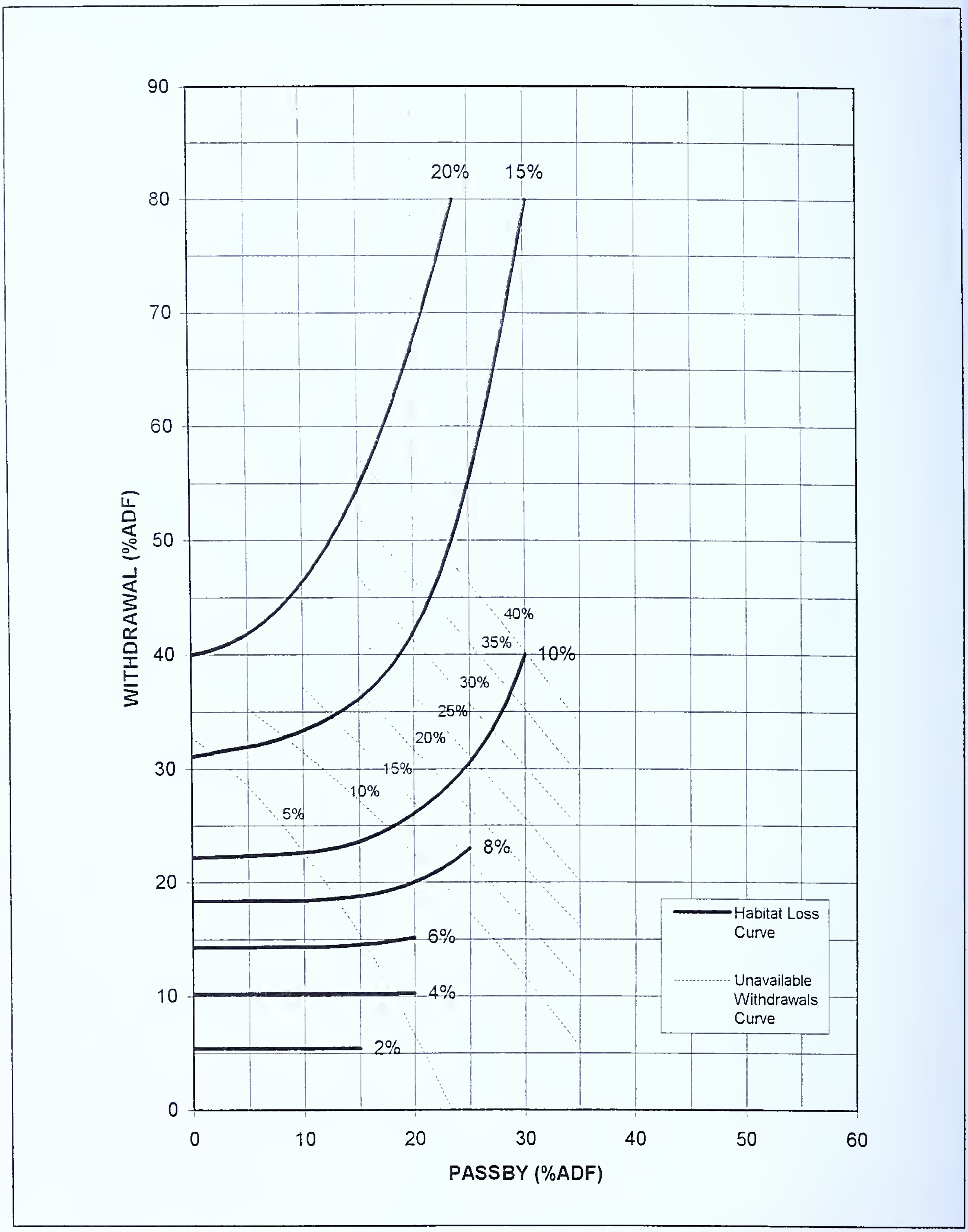

Figure 6.8. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brook Trout

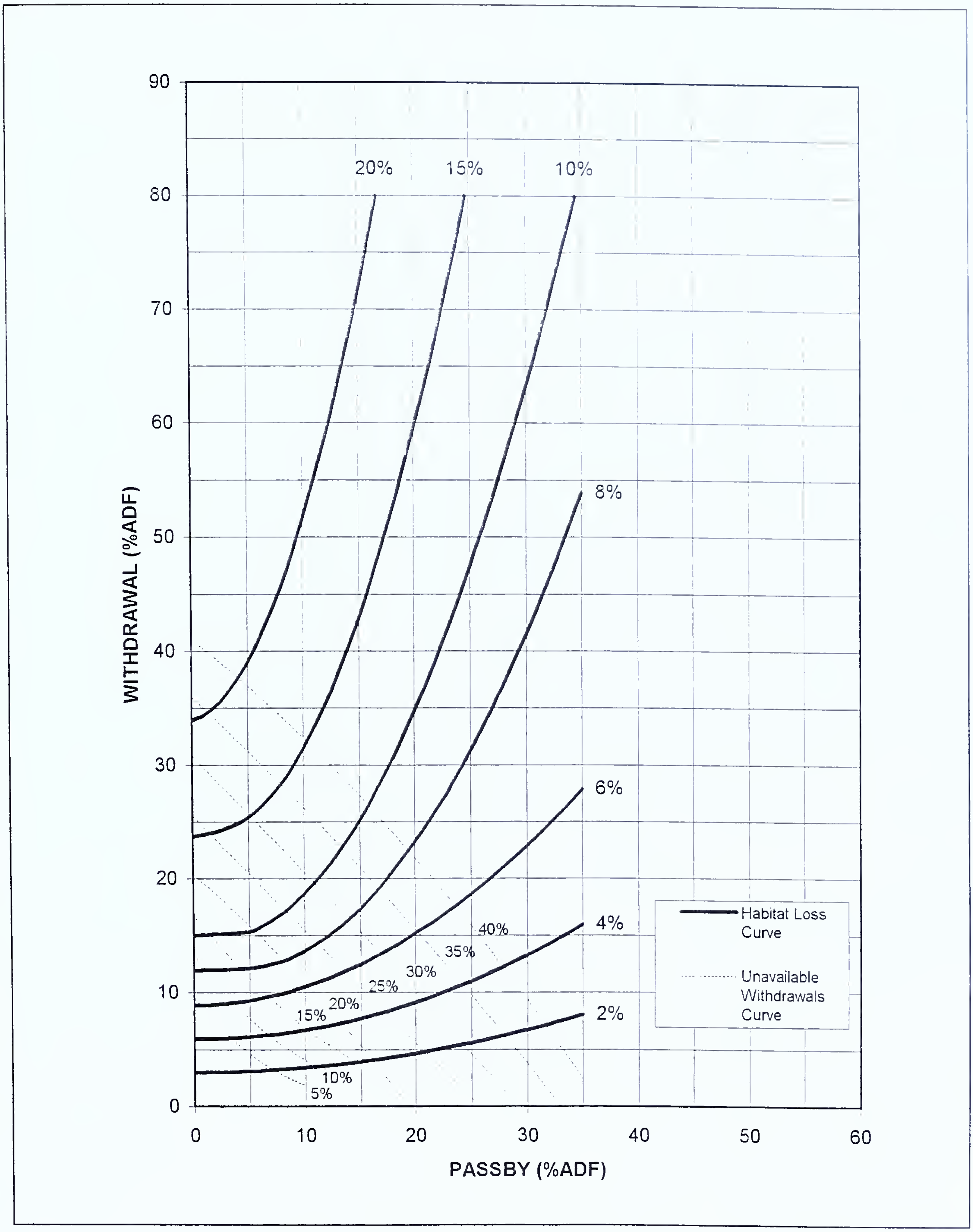

Figure 6.9. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brook Trout

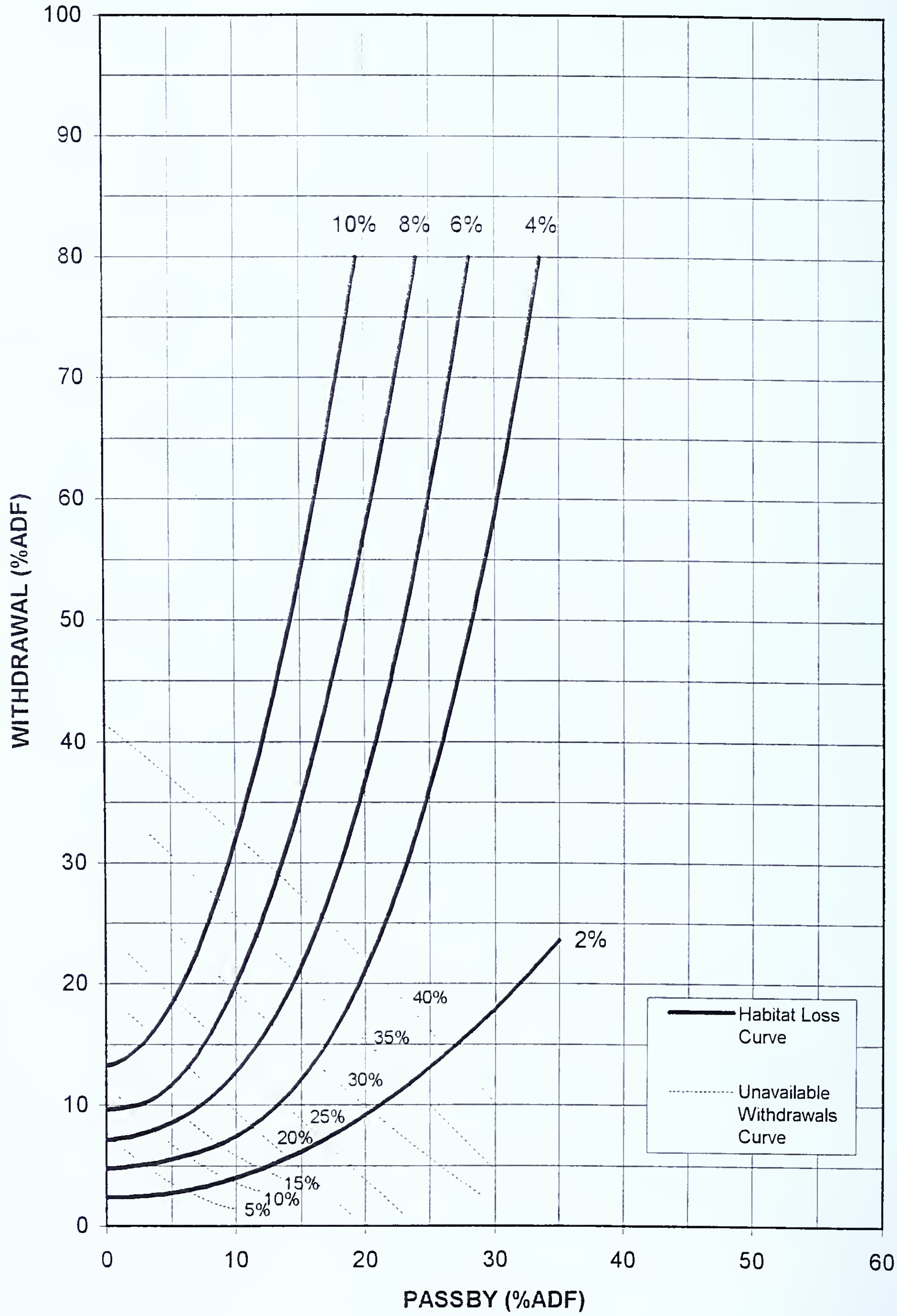

Figure 6.10. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brook Trout

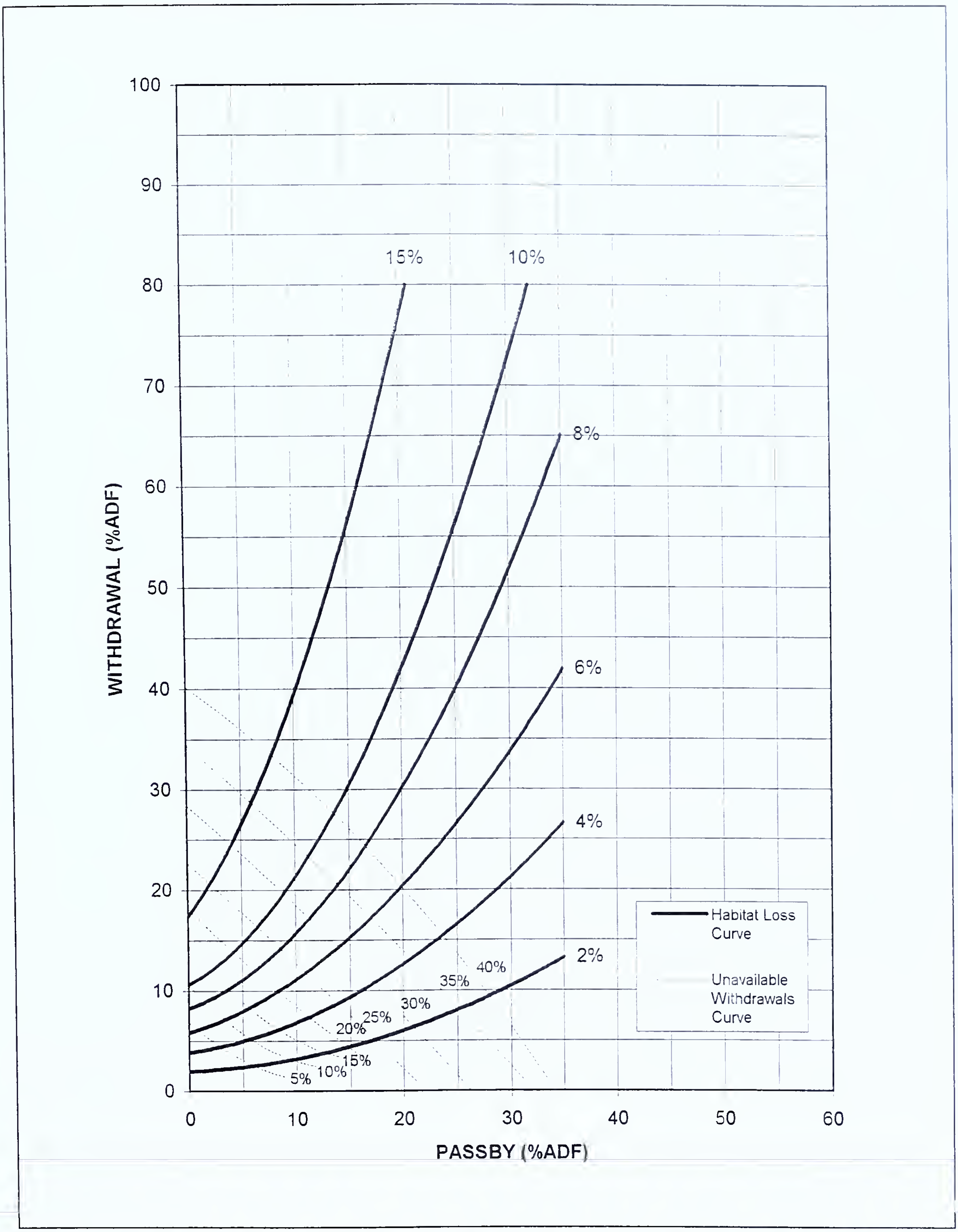

Figure 6.11. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brook Trout

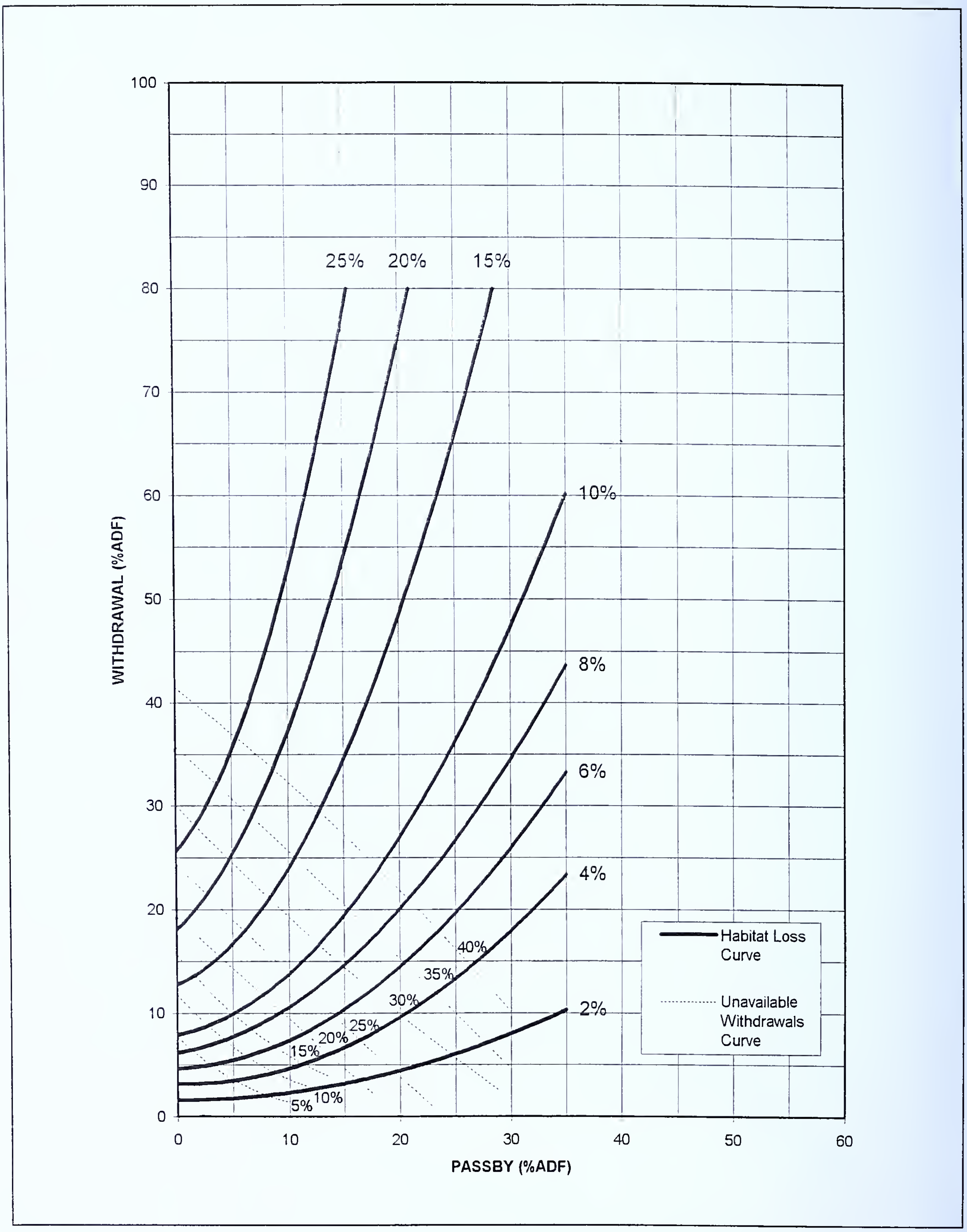

Figure 6.12. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brown and Combined Species

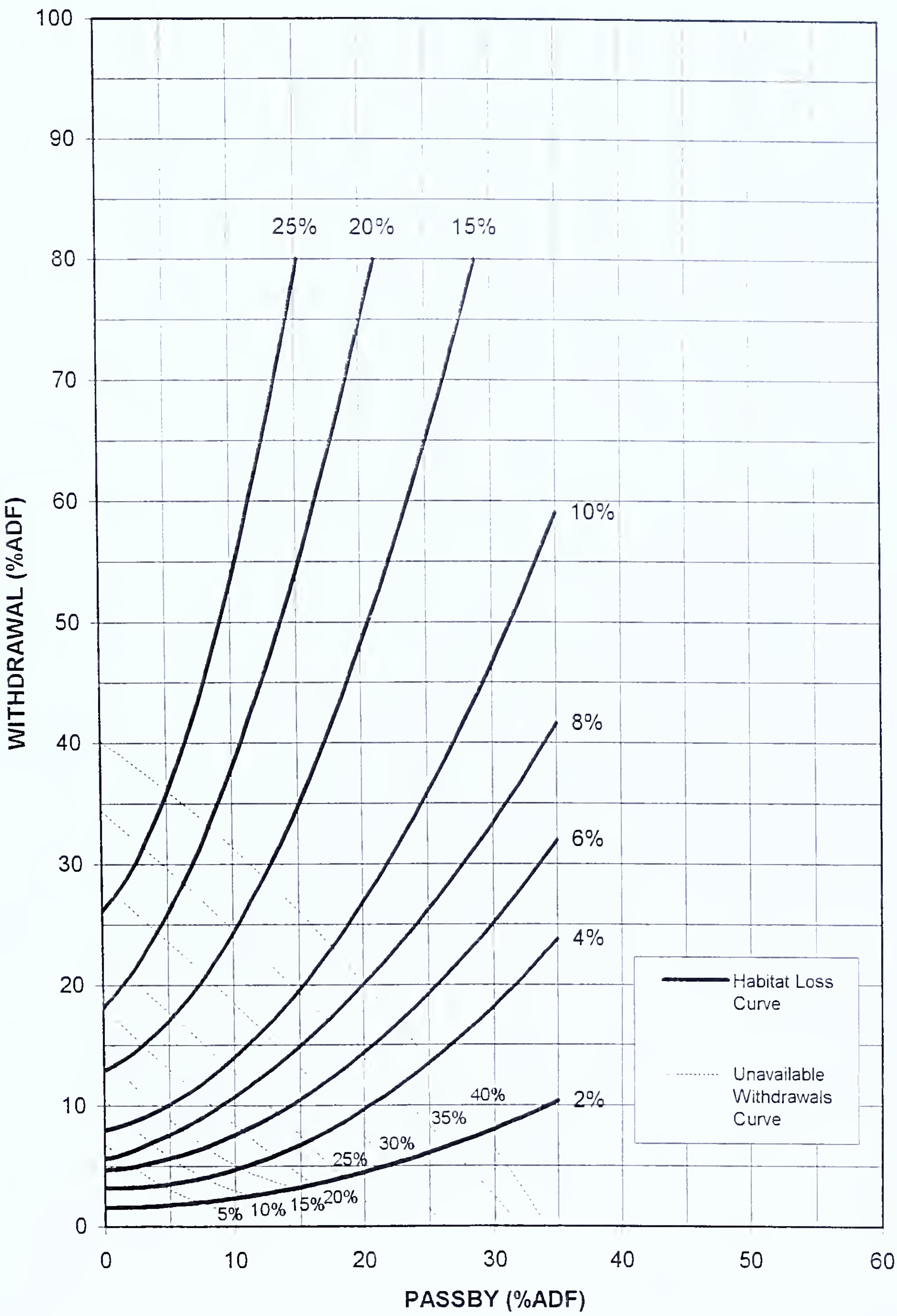

Figure 6.13. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brown and Combined Species

Because of this erratic behavior of the constant habitat impact curves for segment class 2 and 3 sites, only the curves for segment class 1 sites are shown in Figures 6.6 through 6.9. The segment class 2, 3, and 4 study sites should be classified according to prominent physical features, and considered representative of other streams with similar physical features. For example, Penns Creek is characterized by a large cave immediately upstream of the segment class 1 site; Spring Creek (Centre County) is characterized by springs, and a WWTP return flow, which significantly increase the amount of flow in segments 3 and 4; Monocacy Creek and Bushkill Creek are characterized by large amounts of shale in the watershed; Monocacy Creek also has significant underflow at the segment class 2 and 3 study sites. The availability of additional segment class 2, 3, or 4 streams in this region should be determined, and any streams found should be similarly classified by physical features. These streams should be studied and compared to the streams already included.

For the Unglaciated Plateau study region, the curves for segment 1 and 2 were clearly different. Both sets of curves are shown in Figures 6.10 through 6.13.

The effect of the fish species variable on the impact also was investigated. For the Unglaciated Plateau study region, changing the species from brook to brown trout increased the impact from withdrawals by between 2 and 4 percentage points for each combination of withdrawal and passby flow. In the Ridge and Valley Limestone study region, changing brook to brown trout increased the impact by about the same amount. In the Ridge and Valley Freestone study region, the difference between brown trout and combined brown and brook trout is much less than 1 percentage point. In other words, there is so little difference between brown trout and combined brook and brown trout, the two can be used interchangeably. However, in that study region, the difference between brook trout and combined brook and brown trout again was between 2 and 4 percentage points.

A sample summary of the average annual impacts, and the maximum and minimum values of the average impacts, across six representative streams in the Unglaciated Plateau is shown in Table 6.4. This table shows that the range of these values, for each withdrawal and passby flow combination, is small, and similar results were found for most of the representative streams in the respective study regions. In other words, the variation in impact across the region from one stream to another was small, indicating that, while hydrology and stream characteristics were highly variable, impacts to the habitat were fairly consistent within the region. While there is a small range of variation for each of the points plotted on any impact matrix, the habitat impact curves for each study region are very different from the other regions. This supported the basic concept that streams would react similarly within study regions, but differently from one region to another.

Table 6.4. Sample Summary of Range of Impacts, Unglaciated Plateau, Wild Brook Trout

Habitat Impact	10% ADF Withdrawal, 5% ADF Passby	40% ADF Withdrawal, 20% ADF Passby
Maximum	6.95	7.09
Average	6.45	6.49
Minimum	5.97	5.73

An example of the constant habitat impact curves based on the maximum impact measure is shown in Figure 6.14. Comparison of this figure with Figure 6.4 shows the maximum impact for a given withdrawal and passby flow is about 2.5 to 4 times the average impact. The average habitat curves are provided in this report based on the assumption that the long-term average impacts to habitat may result in average impacts to fish biomass of similar magnitude. However, since short-term

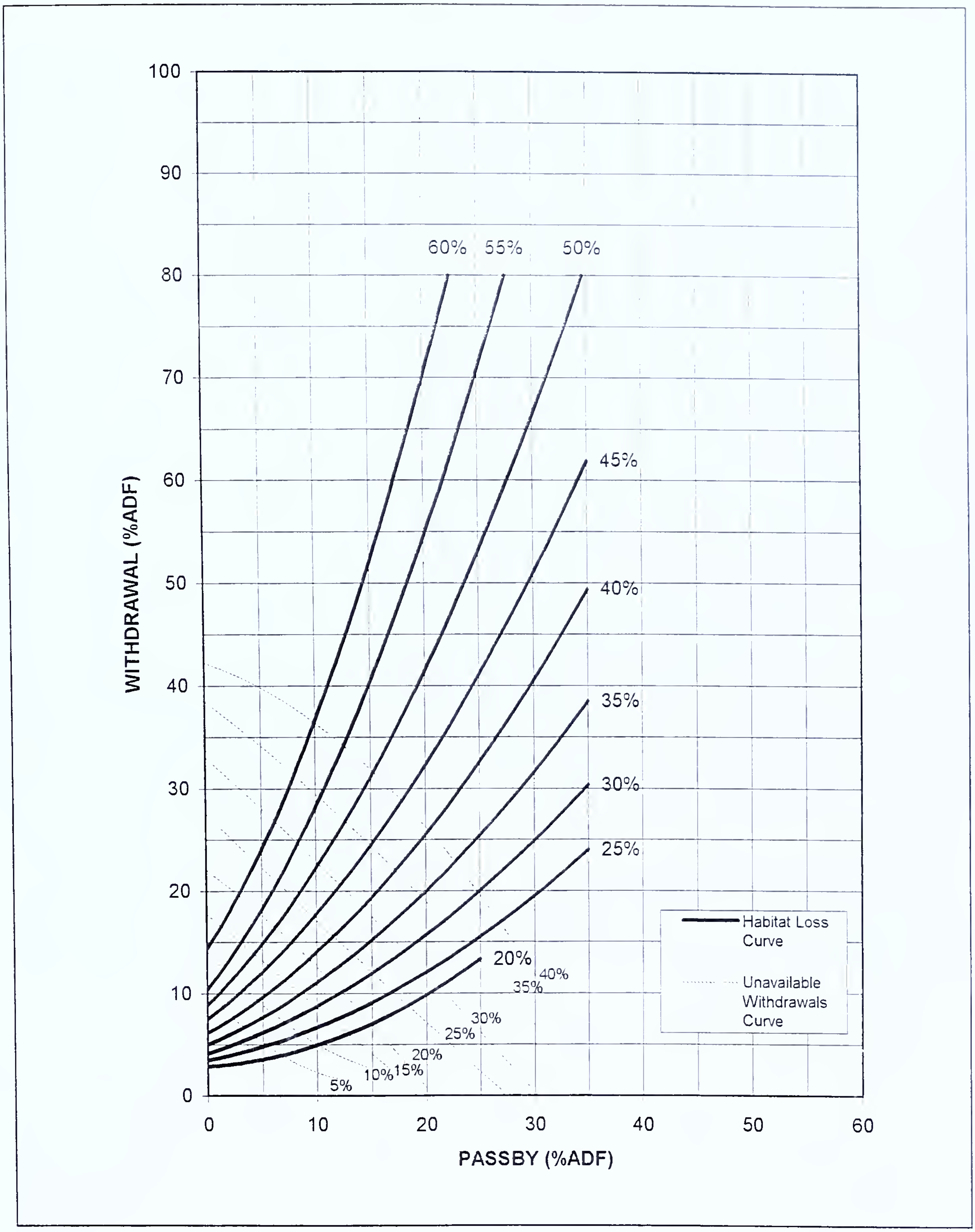

Figure 6.14. Example of Maximum Impact Measure of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone Streams, Wild Brown and Combined Species

maximum impacts to habitat may have more acute effects, both long-term and short-term impacts should be considered when making decisions regarding habitat protection. Corresponding curves could be developed for the 90 percent probability of exceedance impacts on habitat. However, the example of impacts of withdrawals on an individual stream shown in Figure 6.3 shows that the 90 percent probability impact is about three percentage points less than the maximum impact. Other streams showed similar small differences between maximum impact and the 90 percent probability impact. Therefore, there was no advantage in using the 90 percent exceedance impacts rather than the maximum impact curves. The average impact curves show the long-term effect, and the maximum impact curves show the short-term effect.

A project site in the Ridge and Valley study regions should be classified as freestone unless it meets the criteria for limestone. A partial list of limestone streams in Pennsylvania is shown in Table 6.5. Streams were included in this table if they were included in the list of limestone streams prepared by Shaffer (1991), or if they had a total alkalinity greater than 70 mg/L, as shown by PFBC (1994). However, some streams on the list are in the Piedmont Province and these streams should not be used with the Ridge and Valley Limestone impact curves. Some streams shown by PFBC (1994) as having total alkalinity greater than 70 mg/L were not included in this list, because geologic maps showed no limestone rocks in the watershed. Armstrong (1992) lists a large number of trout streams in Pennsylvania, which needs further evaluation before being used for instream flow purposes. Sites on streams not included in Table 6.4 should be classified as limestone on a case-by-case basis, considering the presence of limestone in the upstream watershed, alkalinity, and stream biological characteristics.

In the impact assessment, results showed that the passby flow needed to increase as withdrawals increase, to maintain constant impact. If withdrawals are small, little, if any, passby is required, and the maximum habitat impacts occur during the very low flows. However, as the withdrawals become a larger portion of the flow, passby flows are needed, both to prevent the total depletion of the stream at the lower flows, and to conserve habitat during medium flows. The time when maximum impacts occur shifts from the late summer and fall for small withdrawals to early summer and the winter period, for large withdrawals. Finally, when withdrawals become very large, say over 50 percent of the average daily flow, the passby flows have to be even larger to maintain the same magnitude of impacts, and the most critical periods occur in the winter and spring seasons.

Having developed the family of habitat impact curves, there is the question of which curve to use. Obviously, the curve with the lower percentage impact gives the higher degree of habitat protection. However, as the degree of protection increases, so does the percent of time that withdrawals cannot be made because of passby requirements. The detailed analysis program computes these percentages of time when the full withdrawal cannot be made. These results were plotted on the same graphs (Figures 6.4 through 6.13) with the habitat impact curves. The graphs show that, as the withdrawal increases to levels above 20 percent of the average daily flow, the amount of time that withdrawals will not be possible, either because of flow limitations, or passby requirements, or both, will be 60 to 150 days per year. The exception to this condition is limestone streams included in group 1, which have very substantial low flows.

The determination of which impact curve(s) to use will have to take into account the costs both to the environment and to the withdrawal users. The curves clearly indicate the impact of a specific withdrawal will be less on a larger stream, because the percentage withdrawal is less. However, large streams are generally not available in headwater areas. But, with these curves, the passby flow can be determined for any magnitude of withdrawal at a specific location, to minimize unacceptable impacts on fishery habitat. These curves will allow water purveyors to analyze stream intake alternatives

Table 6.5. Limestone Trout Streams in Pennsylvania

Name of Stream	County	Name of Stream	County
Ott Town Run	Bedford	Buck Run	Franklin
Potter Creek	Bedford	Falling Spring Branch	Franklin
Yellow Creek	Bedford		
		Spring Run	Fulton
Moselem Creek	Berks		
Peters Creek	Berks	Willow Run	Juniata
Spring Creek	Berks	Unnamed Tributary to	
Willow Creek	Berks	Willow Run, nr. Peru Mills	Juniata
Wyomissing Creek	Berks		
		Donegal Creek	Lancaster
Boiling Spring Run	Blair	Eshleman Run	Lancaster
Clover Creek	Blair	Indian Run	Lancaster
		Londonland Run	Lancaster
Cooks Creek	Bucks	Swarr Run	Lancaster
Buffalo Run	Centre	East Branch Mill Creek	Lebanon
Cedar Run	Centre	Mill Creek	Lebanon
Elk Creek	Centre		
Lick Run	Centre	Catasaqua Creek	Lehigh
Little Fishing Creek	Centre	Cedar Creek	Lehigh
Logan Branch	Centre	Coplay Creek	Lehigh
Penns Creek	Centre/Union	Little Lehigh Creek	Lehigh
Pine Creek	Centre	South Branch Saucon Creek	Lehigh
Sinking Creek	Centre	Spring Creek	Lehigh
Slab Cabin Run	Centre	Trout Creek	Lehigh
Spring Creek	Centre		
Spruce Creek	Centre	Antes Creek	Lycoming
Unnamed Tributary to			
Spring Cr., nr. Lemont	Centre	Honey Creek	Mifflin
		Kishacoquillas Creek	Mifflin
Little Valley Creek	Chester	Long Hollow Run	Mifflin
Valley Creek	Chester	Tea Creek	Mifflin
		Penns Creek	Mifflin/Union
Bald Eagle Creek	Clinton		
Cedar Run	Clinton	Allegheny Creek	Northampton
Fishing Creek	Clinton	Bushkill Creek	Northampton
		E. Branch Monocacy Creek	Northampton
Big Spring Creek	Cumberland	Frya Run	Northampton
Cedar Run	Cumberland	Jacoby Creek	Northampton
Green Spring Creek	Cumberland	Monocacy Creek	Northampton
Hogestown Run	Cumberland	Nancy Run	Northampton
Letort Spring Run	Cumberland	Saucon Creek	Northampton
Trindle Spring Run	Cumberland	Shoeneck Creek	Northampton

Sources: Shaffer (1991)
PFBC (1994): Streams with total alkalinity greater than 70 mg/L

NOTE: A few of these streams are located outside the Ridge and Valley Limestone study region.

that meet state fishery protection levels on cold water streams having less than 100 square miles of drainage area. Likewise, the curves will allow the administrative agency to regulate fishery protection on an equitable basis among all applicants requesting water withdrawals.

6.6.3 Regional hydrology

6.6.3.1 Overview

Regional hydrology was developed for three study regions, Ridge and Valley Limestone, Ridge and Valley Freestone, and Unglaciated Plateau, and adjacent areas, for use in the time series impact analysis programs, described in section 6.6.2. Regional hydrology has not been provided for the Piedmont Upland study region at this time, since the IFIM studies for that region are incomplete, and impact analyses for that region may be unreliable because of insufficient study streams. Regional hydrology for the Piedmont study regions can be added when IFIM studies for those areas are completed. Hydrology provided for adjacent areas should be used only for streams flowing into the study area.

The basic assumption in the regional hydrology is that differences in hydrology are related to differences in geology (limestone or freestone), geologic structure, climate, physiography, and topography, and those factors are related to physiographic province and section. While there may be other factors affecting hydrology, those factors are not well understood, and could not be incorporated in this analysis, due to time and cost constraints. The available data supports the assumption.

Development of the regional hydrology is complicated by the following conditions:

- The distribution of limestone, particularly in the Ridge and Valley Physiographic Province (Pa. DER, 1990);
- Limestone also occurs in parts of the Unglaciated Plateau study region in Armstrong, Clarion, and Butler Counties (Pa. DER, 1990);
- Part of the Ridge and Valley Physiographic Province in Lackawanna, Luzerne, Monroe, and Northampton Counties has been glaciated; and
- The Unglaciated Plateau study region encompasses five physiographic sections.

In the Ridge and Valley province, the distribution of limestone affects determination of hydrologic regions because many watersheds, including the gaged streams, have mixed limestone and freestone geology. Limestone valleys are often surrounded by freestone ridges, and some valleys include both limestone and freestone at the surface. For those reasons, the two Ridge and Valley study regions were combined for the purpose of developing regional hydrology procedures. The procedures account for the difference between limestone and freestone by recommending different gages for each rock type. Also, hydrologic regions were defined to account for the expected differences in hydrology between the glaciated and unglaciated parts of the Ridge and Valley Physiographic Province and sections, to the extent possible.

The Appalachian Plateaus Physiographic Province includes nine sections, as shown in Table 2.1 and Plate 1. Note that five sections are unglaciated, and four are glaciated. The Unglaciated Plateau study region includes the five unglaciated sections (section 2.1.3.3).

The procedure for developing regional hydrology included the following steps:

- Select appropriate representative gages for the study regions, and adjacent areas, requiring hydrology;
- Compare the seasonal flow duration curves for each gage within these regions to determine whether pairs of gages are similar;
- For pairs of gages that are hydrologically similar, compare physical data for each pair of gages (Shaw, 1984) to determine whether one gage can be eliminated; and
- Delineate boundaries of hydrologic regions.

6.6.3.2 Selection of gages to develop regional hydrology

The hydrology for the study sites was based on flow data for gages selected to best represent a specific study site (section 5.4). There was no attempt to select gages to represent entire study regions, and no gages were selected for hydrologic regions adjacent to the study regions. For that reason, additional gages were added to the original list (Table 5.8) to ensure that the hydrology of the entire study region was adequately represented.

To determine which gages to include, the USGS ADAPS header file for all gages in Pennsylvania was retrieved and printed out. From this list, a table was prepared that included the following information for all the gaging stations: begin and end date of the record; number of years of record; drainage area; latitude/longitude of the gage; use code; regulation code; and beginning date of the regulation. The use code showed whether the gage is active or inactive, and whether it had been used to develop hydrology for a study stream. The regulation code showed the type of regulation, if any, for each gage (e.g., water supply withdrawal, flood control operation, etc.).

From this list, gages were selected that had at least 10 years of continuous record since 1960, and a drainage area less than 600 square miles. The resulting list included about 220 gages in the entire state. Approximately 20 stations were removed from the list, due to regulation or urbanization, or location outside the study regions.

USGS prepared a map of the state, using a geographic information system (GIS), which included the remaining 200 gages, the physiographic province and section boundaries, and areas underlain by limestone. The physiographic boundaries were obtained from a computer file and a map developed by the Pa. Department of Conservation and Natural Resources (Pa. DCNR), Bureau of Topographic and Geologic Survey (Sevon, 1995). In the Appalachian Plateaus Province, these boundaries are significantly different than the boundaries shown by Pa. DER (1989).

The map prepared by USGS, and the list of gages, were used to further screen gages. This second stage screening produced a list of 56 gages considered to be most representative of each study area. In general, the criteria used in this screening were length and period-of-record, proximity, drainage area size, location, and absence of coal mining or regulation. In general, the gages deleted were those with shorter records, or are presently inactive, or have larger drainage areas. Gages were retained if they were considered representative of different major subbasins and could be easily classified according to geology and/or physiography. This list of gages is shown in Table 6.6.

The data for these gages were compared to see if they were similar, and whether some could be eliminated, and the corresponding hydrologic regions combined, to simplify the regional hydrology procedure. There are two considerations in the decision to combine hydrologic

Table 6.6. Gages Retained After Second Stage Screening

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
01429500	Dyberry Creek near Honesdale, Pa.	10	1943	7	1996	53	64.60
01440400	Brodhead Creek near Analomink, Pa.	10	1957	6	1996	39	65.90
01446600	Martins Creek near East Bangor, Pa.	9	1961	9	1978	18	10.40
01447680	Tunkhannock Creek near Long Pond, Pa.	4	1965	7	1996	32	18.00
01449360	Pohopoco Creek at Kresgeville, Pa.	10	1966	7	1996	30	49.90
01451800	Jordan Creek near Schnecksville, Pa.	2	1966	7	1996	31	53.00
01452500	Monocacy Creek at Bethlehem, Pa.	10	1948	7	1996	48	44.50
01467500	Schuylkill River at Pottsville, Pa.	10	1943	9	1969	26	53.40
01470779	Tulpehocken Creek near Bernville, Pa.	11	1974	7	1996	22	66.50
01470853	Furnace Creek at Robesonia, Pa.	10	1982	6	1996	14	4.18
01472198	Perkiomen Creek at East Greenville, Pa.	8	1981	7	1996	16	38.00
01518862	Cowanesque River at Westfield, Pa.	8	1983	5	1996	14	90.60
01533950	S. Br. Tunkhannock Creek near Montdale, Pa.	9	1960	9	1978	19	12.60
01538000	Wapwallopen Creek near Wapwallopen, Pa.	10	1919	9	1996	76	43.80
01539000	Fishing Creek near Bloomsburg, Pa.	6	1938	7	1996	59	274.00
01541000	West Branch Susquehanna River at Bower, Pa.	10	1913	7	1996	83	315.00
01541500	Clearfield Creek at Dimeling, Pa.	10	1913	7	1996	83	371.00
01543000	Driftwood Br. Sinnemahoning Creek, Sterling Run, Pa.	10	1913	7	1996	83	272.00
01545600	Young Womans Creek near Renovo, Pa.	12	1964	6	1996	32	46.20
01546400	Spring Creek at Houserville, Pa.	11	1984	7	1996	12	58.50
01547700	Marsh Creek at Blanchard, Pa.	10	1955	5	1996	41	44.10
01547800	South Fork Beech Creek near Snow Shoe, Pa.	5	1969	3	1981	13	12.20
01552500	Muncy Creek near Sonestown, Pa.	10	1940	5	1996	56	23.80
01553130	Sand Spring Run near White Deer, Pa.	1	1968	3	1981	14	4.93
01555000	Penns Creek at Penns Creek, Pa.	10	1929	7	1996	67	301.00
01555500	East Mahantango Creek near Dalmatia, Pa.	10	1929	7	1996	67	162.00
01556000	Frankstown Br. Juniata River at Williamsburg, Pa.	10	1916	7	1996	80	291.00
01557500	Bald Eagle Creek at Tyrone, Pa.	10	1944	7	1996	52	44.10
01560000	Dunning Creek at Belden, Pa.	10	1939	7	1996	57	172.00
01564500	Aughwick Creek near Three Springs, Pa.	6	1938	6	1996	59	205.00
01565000	Kishacoquillas Creek at Reedsville, Pa.	10	1939	9	1970	31	164.00
		10	1983	9	1985	2	
		10	1991	9	1992	1	
01565700	Little Lost Creek near Oakland Mills, Pa.	9	1963	3	1981	19	6.52
01567500	Bixler Run near Loysville, Pa.	2	1954	7	1996	43	15.00
01568000	Sherman Creek at Shermans Dale, Pa.	10	1929	7	1996	67	200.00
01569800	Letort Spring Run near Carlisle, Pa.	6	1976	7	1996	21	21.60
01570000	Conodoguinet Creek near Hogestown, Pa.	7	1967	7	1996	30	470.00
01571500	Yellow Breeches Creek near Camp Hill, Pa.	7	1954	7	1996	43	216.00
01573086	Beck Creek near Cleona, Pa.	8	1963	3	1981	19	7.87
01574000	W. Conewago Creek near Manchester, Pa.	10	1928	7	1996	68	510.00
01613050	Tonoloway Creek near Needmore, Pa.	10	1965	6	1996	31	10.70
03007800	Allegheny River at Port Allegany, Pa.	10	1974	7	1996	22	248.00
03009680	Potato Creek at Smethport, Pa.	10	1974	7	1996	22	160.00
03015280	Jackson Run near North Warren, Pa.	10	1962	9	1978	16	12.80

Table 6.6. Gages Retained After Second Stage Screening —Continued

Station Number	Station Name	Begin Date		End Date		Total	Drainage Area
		Month	Year	Month	Year	Years	(sq. mi.)
03015500	Brokenstraw Creek at Youngsville, Pa.	10	1909	7	1996	87	321.00
03017500	Tionesta Creek at Lynch, Pa.	3	1938	10	1979	43	233.00
03020500	Oil Creek at Rouseville, Pa.	10	1932	7	1996	64	300.00
03022540	Woodcock Creek at Blooming Valley, Pa.	9	1974	7	1996	23	31.10
03025000	Sugar Creek at Sugarcreek, Pa.	10	1932	11	1979	48	166.00
03028000	West Branch Clarion River at Wilcox, Pa.	10	1953	7	1996	43	63.00
03034000	Mahoning Creek at Punxsutawney, Pa.	10	1938	7	1996	58	158.00
03042000	Blacklick Creek at Josephine, Pa.	2	1952	7	1996	45	192.00
03042200	Little Yellow Creek near Strongstown, Pa.	9	1960	12	1978	20	7.36
		10	1986	10	1988	3	
03049000	Buffalo Creek near Freeport, Pa.	10	1940	6	1996	56	137.00
03080000	Laurel Hill Creek at Ursina, Pa.	10	1918	7	1996	78	121.00
03104760	Harthegig Run near Greenfield, Pa.	10	1968	4	1981	13	2.26
03106000	Connoquenessing Creek near Zelienople, Pa.	10	1919	7	1996	77	356.00

regions: whether the gages are sufficiently similar, and whether it is reasonable to use one gage to represent the other.

There is no established procedure for comparing two or more gages. However, following a brief review of the literature, and several telephone calls to other hydrologists, the following list of potential approaches to the problem was developed:

- Compare the normalized (csm) flow duration curves graphically, using an assumed acceptable difference between pairs of curves;
- Determine the statistics (mean, standard deviation, skewness) of the daily flow data for each gage, and compare pairs of gages using standard statistical tests (adjustments for serial correlation of the daily flow data are necessary to apply the tests);
- Array the unit flow rates (csm) at selected percentile levels from each probability curve, and analyze the array using a nonparametric test; the Wilcoxon Rank Sum Test and the Kruskal-Wallis Test were considered (Gilbert, 1987), and believed to be inappropriate for this purpose, so this concept was not developed further;
- Perform regional regression analysis of flow values using drainage area, precipitation, and relief (average basin slope) as predictors (R. Vogel, Tufts University, oral communication, June 11, 1996; Helsel and Hirsch, 1992, pp. 52-55);
- Fit an appropriate probability distribution function to each frequency curve, and compare using appropriate statistical tests (R. Vogel, Tufts University, oral communication, June 11, 1996);
- Plot statistics of flow duration curves against drainage area and relief (R. Vogel, Tufts University, oral communication, June 11, 1996); and
- Use a flow duration model developed by Fennessey (1994; R. Vogel, Tufts University, oral communication, June 11, 1996).

Because of time and cost constraints, the first method was used to evaluate similarities among the selected gages. The procedure included the following steps:

- Plot the seasonal flow duration curves for the entire period-of-record for each gage on log-normal probability paper;
- Determine graphically whether pairs of curves are similar, based on whether they differ by less than 20 percent or 30 percent over the entire range of the curve for each season;
- Tabulate whether the curves are similar or dissimilar for each season and each pair of gages; and
- Summarize the table to show which pairs are similar across all seasons.

The following pairs of gages were determined to have similar seasonal flow duration curves:

- Wapwallopen Creek near Wapwallopen and Bald Eagle Creek near Tyrone;
- Pohopoco Creek at Kresgeville and Schuylkill River at Pottsville;

- Young Womans Creek near Renovo and Laurel Hill Creek near Ursina: and
- Connoquenessing Creek near Zelienople and Buffalo Creek near Freeport.

Wapwallopen Creek near Wapwallopen and Bald Eagle Creek near Tyrone are about 110 miles apart, and have different relief ratio, stream length and pattern, and topography, although the channel slopes are similar (Shaw, 1984). The hydrologic similarity appears to be coincidental, so both gages were retained, due to the distance between them.

Pohopoco Creek at Kresgeville and Schuylkill River at Pottsville are about 40 miles apart and in the Ridge and Valley Appalachian Mountain Section. Shaw (1984) includes data for the West Branch Schuylkill River at Cressona and for the Little Schuylkill River above Port Clinton. Both locations are on other branches of the Schuylkill River, and the data may not be representative of the watershed above the Pottsville gage. The West Branch Schuylkill River above Cressona was considered more representative of the watershed upstream from Pottsville. Comparison of the data for that location with data for Pohopoco Creek at Perryville shows the former has a much higher relief ratio and much greater channel slope. There also are differences in channel pattern, geology, and main channel physiography. The topographic relief maps (U.S. Army Corps of Engineers, undated) showed major topographic differences between the two watersheds, so both gages were retained.

Young Womans Creek near Renovo and Laurel Hill Creek near Ursina are about 130 miles apart and have different physiographic and topographic settings. The channel length, relief ratio, channel slope, drainage pattern and main channel characteristics (Shaw, 1984) are all dissimilar. Again, the similarity in hydrology appears coincidental, so both gages were retained.

Buffalo Creek near Freeport and Connoquenessing Creek near Zelienople are both in the Pittsburgh Low Plateau physiographic section and drain adjacent areas. The two watersheds seem to have similar characteristics (Shaw, 1984). Although either gage could be used, Buffalo Creek was retained, since it is more centrally located within the hydrologic region.

A pilot study was conducted to evaluate whether more gages would be similar, based on seasonal flow duration curves, if data for a coincident period-of-record were used in the comparison.

This pilot study used 18 gages selected from Table 6.6 to represent the Ridge and Valley Freestone study region. A plot of the periods-of-record for these 18 gages showed that the maximum number of gages could be included in the comparison if the calendar years 1968-1980 were selected as the period-of-record. Shorter periods-of-record would have questionable hydrologic validity, and would not increase the number of gages. Longer periods-of-record would eliminate gages, and alternative periods-of-record would exchange gages without increasing the total number being compared.

The gages included in these comparisons are:

- Pohopoco Creek at Kresgeville;
- East Mahantango Creek near Dalmatia;
- Frankstown Branch Juniata River at Williamsburg;
- Marsh Creek at Blanchard;
- Jordan Creek at Schnecksville;
- Dunning Creek at Belden;
- Tonoloway Creek near Needmore;
- Maiden Creek Tributary at Lenhartsville;

- Sand Spring Run near White Deer;
- Wapwallopen Creek near Wapwallopen;
- Bald Eagle Creek at Tyrone;
- Sherman Creek at Shermans Dale;
- Fishing Creek near Bloomsburg;
- Aughwick Creek near Three Springs; and
- Penns Creek at Penns Creek.

The following three gages were not included:

- Martins Creek near East Bangor;
- Schuylkill River at Pottsville; and
- Wills Creek below Hyndman.

The comparisons were made, as described previously, except that only summer and fall seasons were considered, and only the 30 percent difference was analyzed. The results showed no pairs of gages were similar across all seasons.

The comparison of flow duration curves using the full period-of-record for each gage showed the following pairs of Ridge and Valley Freestone gages were similar.

- Pohopoco Creek and Schuylkill River; and
- Wapwallopen Creek and Bald Eagle Creek.

The similarity of Pohopoco Creek and Schuylkill River could not be evaluated in this analysis, because the Schuylkill River gage was not in operation for most of the assumed period of record. The other pair of gages are not similar for this period of record, which tends to confirm the previous conclusion that the apparent similarity was coincidence.

The effect of alternative criteria was investigated by making the same comparisons using only the range between 10 percent and 90 percent probability of exceedance. Using this criteria, the following gages are similar across both seasons:

- East Mahantango Creek and Bald Eagle Creek;
- East Mahantango Creek and Sherman Creek;
- Frankstown Branch and Penns Creek;
- Jordan Creek and Maiden Creek Tributary;
- Dunning Creek and Sherman Creek; and
- Wapwallopen Creek and Fishing Creek.

There are at least two criteria for evaluating whether it is reasonable to substitute one gage for the other in each of these six pairs: whether the two regions are adjacent; and whether the geology is similar. The respective regions are adjacent for three pairs of gages:

- East Mahantango Creek and Sherman Creek;
- Jordan Creek and Maiden Creek Tributary; and
- Wapwallopen Creek and Fishing Creek.

The regions represented by each of the other three pairs of gages are separated by one or more intervening regions. Therefore, using one gage to represent both regions will reduce the number of gages, but will not reduce the number of regions. For these cases, the regional hydrology

procedure is simplified only by reducing the number of gages included in the database, which is considered insignificant.

The following conclusions can be drawn from this analysis:

- For the Ridge and Valley Freestone region, use of the assumed coincident period-of-record, rather than the full period-of-record for each gage, does not increase the number of gages that appear to be hydrologically similar, utilizing the assumed criteria for similarity.
- If the rules for determining similarity of gages are modified to include only the range of flows greater than 90 percent probability of exceedance, six pairs of gages are similar, out of a possible 196 pairs. Preliminary analysis shows there is a minor reduction in complexity of the regional hydrology procedure.

Similar analyses of the gages used in the Unglaciated Plateau study region also are expected to show that only a few pairs of gages can be considered similar, and only minor simplification of the regional hydrology procedure is possible. Considering the complexity of the hydrology of the Ridge and Valley Limestone study streams and gages, it is doubtful that the number of gages used in the regional hydrology procedure can be reduced.

The finding that very few pairs of gages are similar implies significant hydrologic variability among hydrologic regions.

6.6.3.3 Delineation of hydrologic regions

To delineate regions, the physiographic province and section boundaries were plotted on the Pennsylvania stream map (Ings and Simmons, 1991). Then the hydrologic region boundaries were delineated on an overlay to the map, based on judgment. Watershed boundaries, physiographic section boundaries, topography, geology, mountain ridges, topographic divides, and streams were used in the delineation of hydrologic boundaries. The topographic relief maps (U.S. Army Corps of Engineers, undated) were used to determine areas with similar topography, and differences in topography were used to delineate appropriate boundaries. The location of limestone was determined from the map prepared by USGS. The map and computer file prepared by Sevon (1995) were used to delineate physiographic boundaries. The boundaries of the Appalachian Plateau Deep Valleys section are being modified (Sevon, in preparation), and those modifications were incorporated (W. D. Sevon, oral communication, April 1997).

Hydrologic regions are designated by a region code, followed by a number. The region codes are based on physiographic province or section, and are shown in Table 6.7. The hydrologic regions were numbered consecutively within each physiographic section. The numbering begins in the northeast corner of the state and proceeds south and west.

The map of the regions is shown in Plate 2. A description of the regions and the gages used for each region are shown in Table 6.8. The final list of gages is shown in Table 6.9.

Table 6.7. Hydrologic Region Designation and Description

Hydrologic Region Designation	Physiographic Province	Comments
GP	Appalachian Plateaus (glaciated)	Includes only streams draining into Ridge and Valley or Unglaciated Appalachian Plateau study regions.
RV	Ridge and Valley	Includes both Appalachian Mountain and Great Valley sections, and glaciated parts of those sections.
RP	New England Province, Reading Prong Section	Includes only streams draining into Ridge and Valley province.
GNL	Piedmont Province, Gettysburg-Newark Lowland Section	Includes only streams draining into Ridge and Valley province.
UP	Appalachian Plateaus (unglaciated)	Includes Deep Valleys, Allegheny Plateau, Allegheny Mountain, High Plateau, and Pittsburgh Low Plateau sections.
SM	Blue Ridge Province South Mountain Section	Includes only streams draining into Ridge and Valley province.

Table 6.8 Hydrology Regions and Gages

Region Designation	Region Description	Stream Gage Number	Stream Gage Name
GP-1	Glaciated Appalachian Plateau Section in Wayne and Wyoming and eastern Lackawanna Counties, Lackawanna River drainage only	01429500	Dyberry Creek near Honesdale
GP-2	Glaciated Appalachian Plateau Section in Pike County, south flowing streams only	01440400	Brodhead Creek near Analomink
GP-3	Glaciated Pocono Plateau Section	01447500	Lehigh River at Stoddartsville
GP-4	Glaciated Appalachian Plateau Section in Susquehanna, Lackawanna, Luzerne, and Columbia Counties, streams flowing into Ridge and Valley physiographic province only	01533950	South Branch Tunkhannock Creek near Montdale
GP-5	Glaciated High Plateau Section, Muncy Creek and Loyalsock Creek drainages	01552500	Muncy Creek near Sonestown
GP-6	Glaciated Appalachian Plateau Section, Lycoming Creek, Pine Creek and Oswayo Creek drainages	01518862	Cowanesque River at Westfield
GP-7	Glaciated Pittsburgh Plateau Section in Erie, Warren, Crawford, Venango, Mercer, Butler and Lawrence Counties	03022540	Woodcock Creek at Blooming Valley
RV-1	Appalachian Mountain Section (Glaciated), Susquehanna River drainage north of glacial boundary (Berwick)	01538000	Wapwallopen Creek near Wapwallopen (modified)
RV-2	Appalachian Mountain Section in Monroe County, east of glacial boundary	01449360	Pohopoco Creek at Kresgeville
RV-3	Great Valley Section east of glacial boundary in Northampton County	01446600	Martins Creek near East Bangor
RV-4	Appalachian Mountain Section, Lehigh River drainage	01449360	Pohopoco Creek at Kresgeville
RV-5	Great Valley Section, Delaware and Lehigh drainage	01452500 01451800	Limestone sections: Monocacy Creek at Bethlehem (modified) Freestone sections: Jordan Creek near Schnecksville
RV-6	Appalachian Mountain Section, Susquehanna River drainage north of Susquehanna River, west to West Branch Susquehanna River and including Loyalsock Cr. drainage; and south of Susquehanna River to crest of Little Mountain and west to Susquehanna River, including Fishing Creek, Mahoning Creek, Chillisquaque Creek, Muncy Creek and part of Shamokin Creek drainage downstream from Weigh Scale	01539000 01567500	Freestone: Fishing Creek near Bloomsburg Limestone: Bixler Run near Loysville
RV-7	Appalachian Mountain Section, Susquehanna River drainage, south of glacial boundary, north of Susquehanna River including Briar Creek drainage; South of Susquehanna River including Nescopeck Creek, Catawissa Creek, Roaring Brook, Mahanoy Creek, and Shamokin Creek drainage upstream from Weigh Scale	01538000	Wapwallopen Creek near Wapwallopen (modified)
RV-8	Appalachian Mountain Section, Schuylkill River drainage	01469500	Little Schuylkill River at Tamaqua
RV-9	Great Valley Section, Schuylkill River drainage	01470779 01470720	Limestone: Tulpehocken Creek near Bernville Freestone. Maiden Creek Tributary at Lenhartsville

Table 6.8. Hydrology Regions and Gages—Continued

Region Designation	Region Description	Stream Gage Number	Stream Gage Name
RV-10	Appalachian Mountain Section, Susquehanna River drainage, south of Line Mountain, and east of Susquehanna River, including Schwaben Creek, Mahantango Creek, Wiconisco Creek, and Powell Creek	01555500	East Mahantango Creek near Dalmatia
RV-11	Great Valley Section, Susquehanna River drainage east of Susquehanna River, including part of Swatara Creek drainage	01573086 01470720	Limestone: Beck Creek near Cleona Freestone: Maiden Creek Tributary at Lenhartsville
RV-12	Appalachian Mountain Section, north of West Branch Susquehanna River and west of Bald Eagle Creek, south and east of crest of Allegheny Front, including parts of Lycoming Creek, Pine Creek, West Branch Susquehanna River and Bald Eagle Creek drainages	01547700	Freestone: Marsh Creek at Blanchard
RV-13	Appalachian Mountain Section, west and south of West Branch Susquehanna River, east of Bald Eagle Creek, north of Juniata River divide, including White Deer Creek, White Deer Hole Creek, Buffalo Creek (Union County), Penns Creek, Middle Creek, West Mahantango Creek, Fishing Creek (Centre and Clinton Counties), and Spring Creek (Centre County) drainages	01546400 01555000 01553130	Limestone: Spring Creek at Houserville Freestone valley: Penns Creek at Penns Creek Freestone mountainous: Sand Spring Run near White Deer
RV-14	Appalachian Mountain Section, Kishacoquillas Creek upstream from Reedsville, and Saddler Run drainages	01565000 01568000 01553130	Limestone: Kishacoquillas Creek at Reedsville (modified) Freestone valley: Sherman Creek at Shermans Dale Freestone mountainous: Sand Spring Run near White Deer
RV-15	Appalachian Mountain Section, Sherman Creek, Buffalo Creek, Little Juniata Creek, Tuscarora Creek (downstream from McCoysville), Cocolamus Creek, Jacks Creek, Kishacoquillas Creek (downstream from Reedsville), and headwaters of Conodoguinet Creek, drainages	01567500 01568000	Limestone: Bixler Run near Loysville Freestone: Sherman Creek at Shermans Dale
RV-16	Great Valley Section, Cumberland and Franklin counties	01569800 01571500 01568000	Limestone with significant springs (Flippo, 1974): Letort Spring Run near Carlisle, (modified), and add spring flow; Limestone, no significant springs: Yellow Breeches Creek near Camp Hill Freestone: Sherman Creek at Shermans Dale
RV-17	Appalachian Mountain Section, north of Juniata River from Granville (Mifflin County) to crest of Tussey Mountain (except Saddler Run); south of Juniata River, to Potomac River divide, west of RV-14 and RV-15 to crest of Tussey Mountain and Evitts Mountain; including Buffalo Creek (Perry County), Tuscarora Creek (upstream from McCoysville), Aughwick Creek, Raystown Branch Juniata River (downstream from Everett), Standing Stone Creek and Shaver Creek drainages	01564500 01567500	Freestone: Aughwick Creek near Three Springs Limestone: Bixler Run near Loysville

Table-6.8. Hydrology Regions and Gages—Continued

Region Designation	Region Description	Stream Gage Number	Stream Gage Name
RV-18	Appalachian Mountain Section, Potomac basin divide south to Maryland line, east of Town Mountain, including Licking Creek, Tonoloway Creek and Bear Creek drainages	01613050 01546400	Freestone: Tonoloway Creek at Needmore Limestone: Bixler Run near Loysville
RV-19	Appalachian Mountain section, parts of Little Juniata River, and Frankstown Branch and Raystown Branch Juniata River drainages; west of crest of Tussey Mountain, east of crest of Bald Eagle Mountain, Canoe Mountain, Lock Mountain, Dunning Mountain, and Evitts Mountain; south of West Branch Susquehanna River divide; north of Raystown Branch Juniata River; including Spruce Creek, Sinking Run, Clover Creek, Piney Creek, Snakespring Valley Run, and part of Yellow Creek (Bedford County) drainages	01556000	Limestone: Spring Creek at Houserville Freestone: Dunning Creek at Belden
RV-20	Appalachian Mountain Section, parts of Little Juniata River and Frankstown Branch Juniata River drainages; west of crest of Bald Eagle Mountain, Canoe Mountain, Lock Mountain and Dunning Mountain; and east of crest of Allegheny Front	01546400 01560000	Limestone: Bixler Run near Loysville Freestone: Bald Eagle Creek at Tyrone
RV-21	Appalachian Mountain Section, west of crest of Dunning Mountain, Evitts Mountain, and Tussey Mountain, east of crest of Allegheny Front, south of Frankstown Branch divide, north of Potomac basin divide, including all of Raystown Branch Juniata River drainage upstream of Bedford, and Shover's Run and Cove Creek drainages	01546400 01560000	Limestone: Bixler Run near Loysville Freestone: Dunning Creek at Belden
RV-22	Appalachian Mountain Section, Potomac basin divide south to Maryland line, west of Town Mountain to boundary of Ridge and Valley Province, including Sideling Hill Creek, Town Creek, Flintstone Creek, Evitts Creek, and part of Wills Creek drainages	01601000 01567500	Freestone: Wills Creek below Hyndman Limestone: Bixler Run near Loysville
RP-1	Reading Prong Section, Lehigh, Northampton, and Berks Counties	01470853	Furnace Creek at Robesonia (modified)
GNL-1	Gettysburg-Newark Lowland Section in northern Bucks County, Durham Creek drainage	01472198	Perkiomen Creek at East Greenville
GNL-2	Gettysburg-Newark Lowland Section in Lebanon, Dauphin, and York Counties, north flowing streams only, including parts of Swatara Creek and Yellow Breeches Creek drainages	01574000	West Conewago Creek near Manchester
SM-1	South Mountain Section in Cumberland, York, Adams, and Franklin Counties	01568000	Sherman Creek at Shermans Dale

Table 6.8. Hydrology Regions and Gages—Continued

Region Designation	Region Description	Stream Gage Number	Stream Gage Name
UP-1	Deep Valley Section, in Susquehanna drainage, including parts of Lycoming, Pine Creek and Kettle Creek drainage	01545600	Young Womans Creek near Renovo
UP-2	Deep Valley Section as defined by Sevon (in preparation), Allegheny River drainage, south of glacial boundary and New York state line; excluding Potato Creek drainage upstream from Farmers Valley, and part of Allegheny River drainage upstream from Port Allegany and west of Allegheny River	03007800	Allegheny River at Port Allegany
UP-3	Deep Valleys Section as defined by Sevon (in preparation), Potato Creek drainage upstream from Farmers Valley, and part of Allegheny River drainage upstream from Port Allegany and west of the Allegheny River	03009680	Potato Creek at Smethport
UP-4	Deep Valley Section, Sinnemahoning Creek drainage	01543000	Driftwood Branch Sinnemahoning Creek at Sterling Run
UP-5	Allegheny Plateau Section, including West Branch Susquehanna River, Beech Creek, and Black Moshannon Creek drainages	01547800	South Fork Beech Creek near Snow Shoe
UP-6	Pittsburgh Low Plateau Section, West Branch Susquehanna River, parts of Moshannon Creek and Bennett Branch Sinnemahoning Creek drainages	01541000	West Branch Susquehanna River at Bower, except for main stem of Clearfield Creek downstream from Glendale Lake
UP-7	Allegheny Mountain Section, Conemaugh River drainage	03042000	Freestone and limestone: Blacklick Creek at Josephine
UP-8	Allegheny Mountain Section, Wills Creek drainage	01601000	Wills Creek below Hyndman
UP-9	Allegheny Mountain Section, Youghiogheny River and Monongahela River drainages	03080000	Freestone and limestone: Laurel Hill Creek at Ursina
UP-10	High Plateau Section as defined by Sevon (in preparation), Allegheny River (downstream from Kinzua Dam) and Tionesta Creek drainage in southwestern McKean, Warren, Elk and Forest Counties	03017500	Tionesta Creek at Lynch
UP-11	High Plateau Section, part of Clarion River and Redbank Creek drainages, (Pa. DEP subbasins 17A, parts of 17B and 17C)	03028000	West Branch Clarion River at Wilcox
UP-12	High Plateau Section, Oil Creek, parts of Sugar Creek and Pithole Creek drainages (Pa. DEP Subbasin 16E, part of 16D and 16G)	03020500	Freestone and limestone: Oil Creek at Rouseville
UP-13	Pittsburgh Low Plateau Section, including Mahoning Creek, Crooked Creek, parts of Redbank Creek and Clarion River drainages	03034000	Freestone and limestone: Mahoning Creek at Punxsutawney
UP-14	Pittsburgh Low Plateau Section, including Slippery Rock Creek, Connoquenessing Creek, Buffalo Creek, Conemaugh River, Sewickley Creek, and part of Youghiogheny River drainages (Pa. DEP subbasins 18B, 18F, 19A, 19D, 20C)	03049000	Freestone and Limestone: Buffalo Creek near Freeport

Table 6.9. Final List of Gages Used in Regional Hydrology

Station Number	Station Name	Begin Date Month	Begin Date Year	End Date Month	End Date Year	Total Years	Drainage Area (sq. mi.)
01429500	Dyberry Creek near Honesdale, Pa.	10	1943	7	1996	53	64.60
01440400	Brodhead Creek near Analomink, Pa.	10	1957	6	1996	39	65.90
01446600	Martins Creek near East Bangor, Pa.	9	1961	9	1978	18	10.40
01447500	Lehigh River at Stoddartsville, Pa.	10	1943	7	1996	53	91.70
01449360	Pohopoco Creek at Kresgeville, Pa.	10	1966	7	1996	30	49.90
01451800	Jordan Creek near Schnecksville, Pa.	2	1966	7	1996	31	53.00
01452500	Monocacy Creek at Bethlehem, Pa.	10	1948	7	1996	48	44.50
01469500	Little Schuylkill River at Tamaqua, Pa.	10	1919	7	1996	77	42.90
01470720	Maiden Creek Tributary at Lenhartsville, Pa.	10	1965	4	1981	16	7.46
01470779	Tulpehocken Creek near Bernville, Pa.	11	1974	7	1996	22	66.50
01470853	Furnace Creek at Robesonia, Pa.	10	1982	6	1996	14	4.18
01472198	Perkiomen Creek at East Greenville, Pa.	8	1981	7	1996	16	38.00
01518862	Cowanesque River at Westfield, Pa.	8	1983	5	1996	14	90.60
01533950	S. Br. Tunkhannock Creek near Montdale, Pa.	9	1960	9	1978	19	12.60
01538000	Wapwallopen Creek near Wapwallopen, Pa.	10	1919	12	1978	78	43.80
01539000	Fishing Creek near Bloomsburg, Pa.	6	1938	7	1996	59	274.00
01541000	West Branch Susquehanna River at Bower, Pa.	10	1913	7	1996	83	315.00
01543000	Driftwood Br. Sinnemahoning Creek, Sterling Run, Pa.	10	1913	7	1996	83	272.00
01545600	Young Womans Creek near Renovo, Pa.	12	1964	6	1996	32	46.20
01546400	Spring Creek at Houserville, Pa.	11	1984	7	1996	12	58.50
01547700	Marsh Creek at Blanchard, Pa.	10	1955	5	1996	41	44.10
01547800	South Fork Beech Creek near Snow Shoe, Pa.	5	1969	3	1981	13	12.20
01552500	Muncy Creek near Sonestown, Pa.	10	1940	5	1996	56	23.80
01553130	Sand Spring Run near White Deer, Pa.	1	1968	3	1981	14	4.93
01555000	Penns Creek at Penns Creek, Pa.	10	1929	7	1996	67	301.00
01555500	East Mahantango Creek near Dalmatia, Pa.	10	1929	7	1996	67	162.00
01557500	Bald Eagle Creek at Tyrone, Pa.	10	1944	7	1996	53	44.10
01560000	Dunning Creek at Belden, Pa.	10	1939	7	1996	57	172.00
01564500	Aughwick Creek near Three Springs, Pa.	6	1938	6	1996	59	205.00
01565000	Kishacoquillas Creek at Reedsville, Pa.	10 10 10	1939 1983 1991	9 9 9	1970 1985 1992	31 2 1	164.00
01567500	Bixler Run near Loysville, Pa.	2	1954	7	1996	43	15.00
01568000	Sherman Creek at Shermans Dale, Pa.	10	1929	7	1996	67	200.00
01569800	Letort Spring Run near Carlisle, Pa.	6	1976	7	1996	21	21.60
01571500	Yellow Breeches Creek near Camp Hill, Pa.	7	1954	7	1996	43	216.00
01573086	Beck Creek near Cleona, Pa.	8	1963	3	1981	19	7.87
01574000	W. Conewago Creek near Manchester, Pa.	10	1928	7	1996	68	510.00

Table 6.9. Final List of Gages Used in Regional Hydrology—Continued

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
01601000	Wills Creek below Hyndman, Pa.	6	1951	9	1967	17	146.00
01613050	Tonoloway Creek near Needmore, Pa.	10	1965	6	1996	31	10.70
03007800	Allegheny River at Port Allegany, Pa.	10	1974	7	1996	22	248.00
03009680	Potato Creek at Smethport, Pa.	10	1974	7	1996	22	160.00
03017500	Tionesta Creek at Lynch, Pa.	3	1938	10	1979	43	233.00
03020500	Oil Creek at Rouseville, Pa.	10	1932	7	1996	64	300.00
03022540	Woodcock Creek at Blooming Valley, Pa.	9	1974	7	1996	23	31.10
03028000	West Branch Clarion River at Wilcox, Pa.	10	1953	7	1996	43	63.00
03034000	Mahoning Creek at Punxsutawney, Pa.	10	1938	7	1996	58	158.00
03042000	Blacklick Creek at Josephine, Pa.	2	1952	7	1996	45	192.00
03049000	Buffalo Creek near Freeport, Pa.	10	1940	6	1996	56	137.00
03080000	Laurel Hill Creek at Ursina, Pa.	10	1918	7	1996	78	121.00

During the delineation of boundaries, two gages (Wills Creek below Hyndman, and Maiden Creek Tributary at Lenhartsville) were added to the list, shown in Table 6.5, to represent certain hydrologic regions. Also, Tunkhannock Creek near Long Pond was replaced by Lehigh River at Stoddartsville, and Little Schuylkill River at Tamaqua was substituted for Schuylkill River at Pottsville in region RV-8. Eleven gages included in Table 6.6 were not used in the final determination of regions.

The delineation of boundaries considered the location of study streams and gages used to develop hydrology for those study streams. In most cases, the study streams are within a hydrologic region where the same gage was used for determining study site hydrology as described in section 5.4. For a few study streams, shown in Table 6.10, a different gage is recommended. In those cases, the hydrology of the study stream(s) was recomputed. For study streams where the revised hydrology was significantly different, the hydraulic simulations and RMWUA versus flow relationships were revised in accordance with the simulation criteria described in section 5.7. The revised hydrology and RMWUA relationships were used in the impact analysis studies described in section 6.6.2.4.

Table 6.10. Study Streams Revised for Regional Hydrology

Region	Study Stream	New Gage
Ridge and Valley Limestone, Group 1	Penns Creek	Spring Creek at Houserville with Penns Creek at Penns Creek
Ridge and Valley Limestone, Group 2	Boiling Spring Run	Bixler Run near Loysville
	Long Hollow Run	Bixler Run near Loysville
Unglaciated Plateau	Benner Run	South Fork Beech Creek near Snow Shoe
	Dunlap Run	West Branch Susquehanna at Bower
	Meyers Run	South Fork Beech Creek near Snow Shoe
	Mill Run	Driftwood Branch Sinnemahoning Creek at Sterling Run

No gages are available to represent the watersheds underlain by the Vanport limestone in Armstrong, Clarion, and Butler Counties. This limestone is not expected to affect the hydrology, because of its characteristics (L. Taylor, SRBC, oral communication; S. Runkle, Pa. DEP, oral communication). For that reason, it should be ignored in determining hydrology for study streams in these counties.

In Table 6.8, the region description provides guidance for determining the appropriate region. The hydrologic region includes the watersheds shown in the description, and may include other streams not specifically noted. Also, the description may imply overlap among regions that is not intended. Because of the difficulty of describing complex regional boundaries, the appropriate regions should be determined by locating the actual stream on the map in Plate 2.

Some of the gage data were modified, because of unusual conditions, as described in section 5.4 and Appendix D, for use in the regional hydrology procedure. Those cases are designated as "modified" in the last column of Table 6.8.

6.6.3.4 Regional hydrology application

For most streams, the ADF and median monthly flows are computed from the unit flow rates (csm) for the appropriate gage by multiplying by an appropriate drainage area at the project location. The gage data for some gages may need to be modified, as described in section 5.4 and Appendix E, to compute hydrology for project streams. If the watershed at the project site is underlain by only one type of geology, the hydrology can be computed using only one gage, and the drainage area at the project site. If the watershed includes significant amounts of different geology (for example,

limestone and freestone, or different physiographic sections), the drainage area underlain by each type of geology or each physiographic type must be determined. Then the ADF and median monthly flows can be computed by multiplying the unit flow rate (csm) for each appropriate gage by the appropriate drainage area above the project site, and summing the resulting values for each type of geology. As discussed previously, the Vanport limestone in Armstrong, Butler, and Clarion Counties should be ignored in determining hydrology for study streams.

These regional hydrology computations assume there are no unusual conditions affecting the hydrology of the project stream. For some project streams, the computed flows need to be adjusted for the effects of significant springs or caverns, or for existing water withdrawals or wastewater treatment plant (WWTP) flows. The presence of significant springs can be determined from Flippo (1974). The presence of existing water withdrawals or WWTP flows can be determined from Pa. DEP files.

To use the regional hydrology procedure, locate the project site, using the map shown in Plate 2 and Table 6.8, and determine the appropriate hydrologic region. Then determine the type(s) of geology (or physiography) underlying the watershed upstream from the project site, and determine the drainage area for each type. Next, determine whether adjustments for the effect of springs are necessary from Flippo (1974), or other sources, and the magnitude of the adjustment. Also, determine whether adjustments for WWTP flows are necessary, and the magnitude of the adjustment. Then compute ADF, and median monthly flow time series, using the appropriate gage(s) for the geology/physiography type, add adjustments for WWTP flows and springs, and subtract adjustments for withdrawals. These calculations have to be performed prior to entering the impact analysis program. The data must be entered in units of cfs.

Pending additional studies, different types of geology should be considered when estimating ADF or median monthly flows only if the drainage area underlain by the nondominant geology, or physiography, exceeds 20 percent of the drainage area at the project site. If the nondominant geology is less than 20 per cent of the drainage area, it is expected to have little effect on the median monthly flows and the flow duration curve at the study site. If the nondominant geology exceeds 20 per cent of the drainage area, it may have significant effect on the hydrology at the study site.

6.6.4 Impact analysis using flow and associated habitat duration

6.6.4.1 Analysis procedure

Flow and associated habitat duration impact analysis can be used in developing statewide policies and procedures for managing the impact of withdrawals on fishery resources, and also can be used for site-specific analyses of impacts. The impact analysis procedure, described in this section, addresses the first purpose.

This method combines daily flow duration analyses for a study stream with habitat versus flow relationships to obtain associated habitat duration. The percentage reduction in habitat across a range of flows represents the impact of withdrawals. Flows and withdrawals are expressed as a percentage of ADF, or as unit flows (csm), so that levels of impact and passby flows can be compared across streams within a study region. Impacts and passby flows can be averaged across a region, if appropriate.

The procedure is shown schematically in Figure 6.15. Seasonal flow duration relationships for existing conditions are developed for each study site, using procedures described in section 5.4. One or more levels of withdrawal are selected, and expressed as a percentage of ADF. The

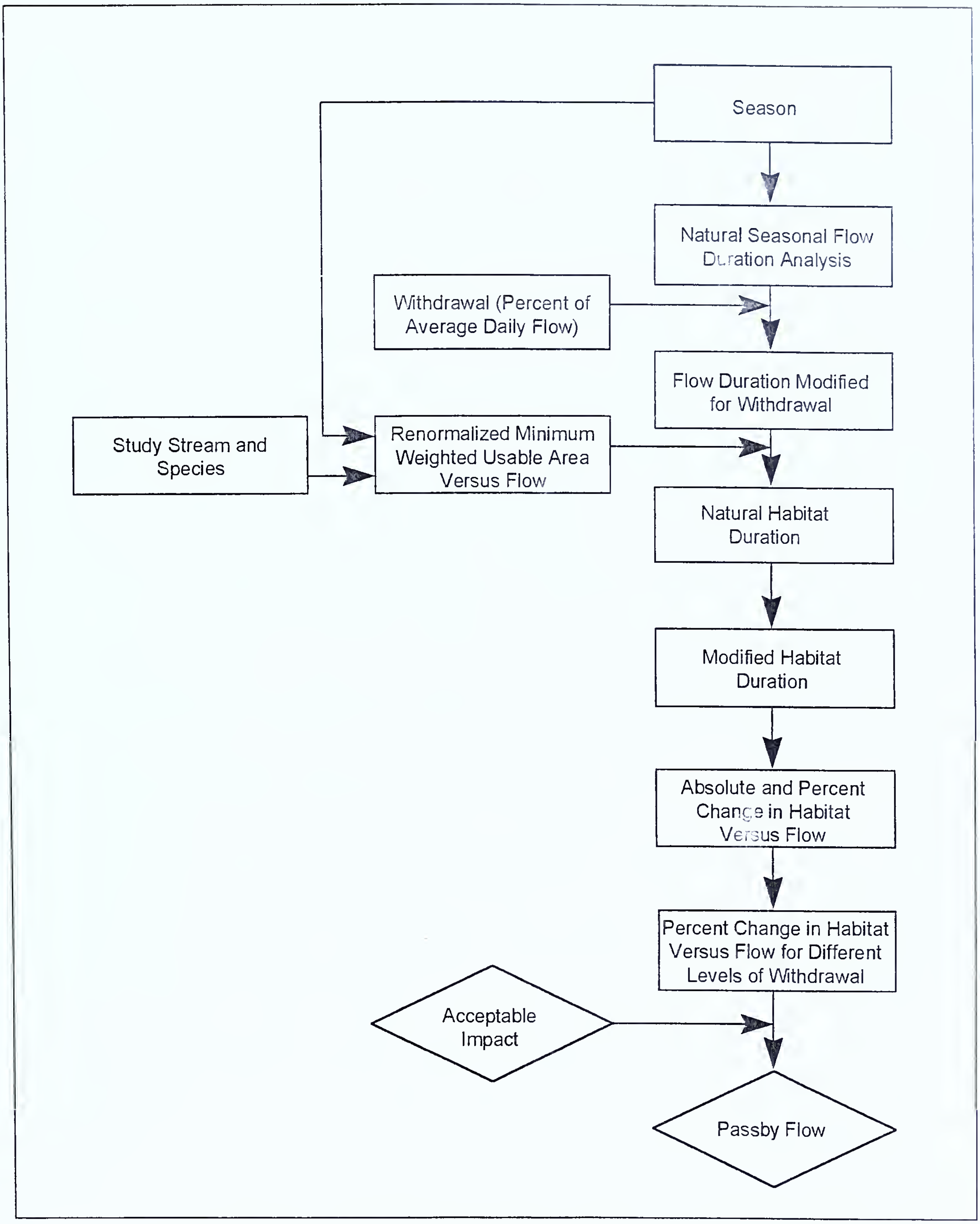

Figure 6.15. Flow and Associated Habitat Duration Impact Analysis Procedures

existing conditions associated habitat durations are developed for each stream from the existing conditions flow duration by determining habitat from the RMWUA versus flow relationship at several flows.

The impacted seasonal flow durations are computed by subtracting selected withdrawal(s) from the existing conditions flow durations. The associated habitat duration is developed from the habitat available at the impacted flow at selected probabilities for each level of withdrawal, as illustrated schematically in Figure 6.16. For each withdrawal, the change in habitat is determined for each selected probability, and expressed as a percentage. Finally, the percentage change in habitat is plotted versus flow for each level of withdrawal. The passby flow for a given withdrawal equals the lowest level of flow for which habitat reduction is equal to a specified level.

The habitat change graphs can be used to evaluate the effect of alternative passby flows and withdrawals by plotting passby flows required versus specified levels of impact for each level of withdrawal. The required passby flow for any level of withdrawal and any level of impact can be determined from the respective graphs for each study stream. The values of the passby flows for any specified level of impact can be tabulated for different streams within a stream class to facilitate decisions regarding acceptable level of impact and appropriate passby flows. The effects of establishing different levels of regulatory passby flow for a given level of withdrawal on the fishery can be developed from these graphs. Then the impact on the water supply utility can be estimated, and used to evaluate tradeoffs between effects of different levels of withdrawal and passby flow on both instream and withdrawal uses.

If this procedure was used, the variability of impacts and passby flows for the study sites within each class could be used to statistically verify the assumptions of the stream classification scheme. The validity of the assumption that all the reproducing trout streams in a study region respond similarly to flows and withdrawals could be verified.

The determination of the relationships among flows, withdrawals, and impact can be performed graphically or in a tabular form. The analysis has been programmed into an Excel spreadsheet format.

6.6.4.2 Flow and associated habitat duration impact analysis results

Impact analysis has been performed for brook trout, brown trout, and both species combined. Separate analyses were performed for each season, based on the life stages present. The seasons were determined as discussed in section 6.6.2, except that the analyses made thus far, assumed that the fall season included only the months of October and November. The analyses can be easily modified to include the remaining months in the fall season. Flow duration curves were developed using daily flow data for each season. In these analyses, withdrawal levels of 5, 10, and 15 percent of ADF were used, but any level of withdrawal can be used.

An example impact calculation is shown in Table 6.11. The impacted RMWUA could not be determined for certain high probability flows, because the impacted flow (existing conditions flow minus withdrawal) is less than any historical flow. An example habitat change versus flow relationship is shown in Figure 6.17. Certain values from the graph are summarized in Table 6.12. The specified levels of reduction were selected arbitrarily for illustration only.

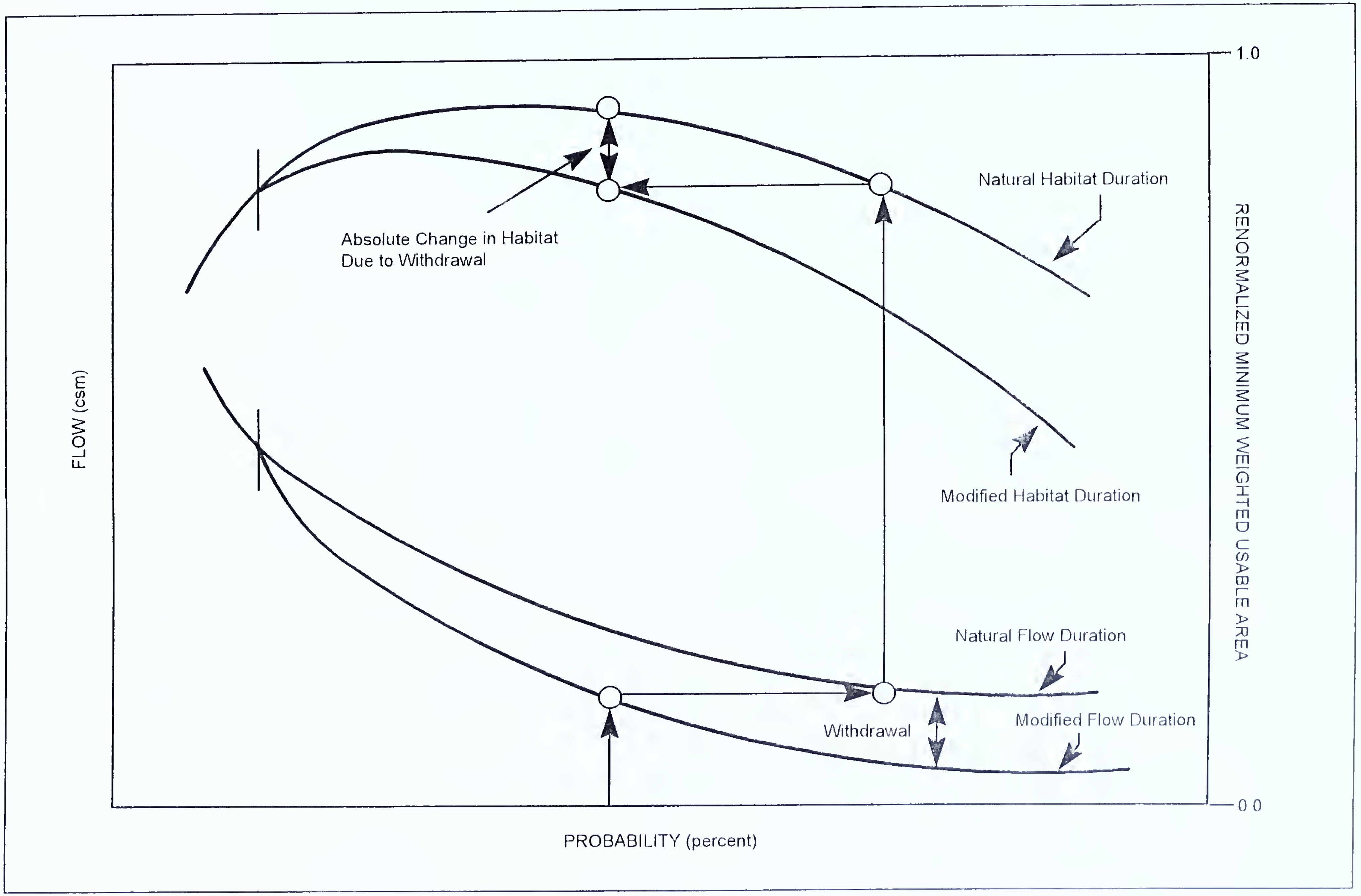

Figure 6.16. Schematic of Computation of Impact of Withdrawal on Habitat

Table 6.11. Sample Computation of Impact, Bear Run, Union County, Brook Trout, Summer Season

Flow Duration and Normalized Minimum Habitat
SEASON Summer (July-Sept)
Species Brook Trout
Stream Bear Run
Annual Mean = 4.120
% of ADF Withdrawal = 5%
% of ADF Withdrawal = 10%
% of ADF Withdrawal = 15%

Natural Flow			RMWUA	Impact of 5% ADF Withdrawal				Impact of 10% ADF Withdrawal				Impact of 15% ADF Withdrawal			
	Flow	Percent		Flow		RMWUA Difference		Flow		RMWUA Difference		Flow		RMWUA Difference	
Probability	(cfs)	Annual Mean		(cfs)	RMWUA	Absolute	Percent	(cfs)	RMWUA	Absolute	Percent	(cfs)	RMWUA	Absolute	Percent
100.00	0.39	9.49	0.270	0.18	No Value			0.00	No Value			0.00	No Value		
97.91	0.44	10.78	0.305	0.24	No Value			0.03	No Value			0.00	No Value		
95.99	0.53	12.94	0.362	0.33	No Value			0.12	No Value			0.00	No Value		
94.40	0.58	14.02	0.391	0.37	No Value			0.17	No Value			0.00	No Value		
89.88	0.67	16.17	0.431	0.46	0.315	-0.116	-26.90	0.25	No Value			0.05	No Value		
83.78	0.76	18.33	0.454	0.55	0.373	-0.081	-17.90	0.34	No Value			0.14	No Value		
70.65	0.89	21.56	0.473	0.68	0.435	-0.037	-7.86	0.48	0.326	-0.147	-31.07	0.27	No Value		
53.60	1.02	24.80	0.500	0.82	0.463	-0.037	-7.42	0.61	0.412	-0.088	-17.52	0.40	0.278	-0.222	-44.32
43.06	1.15	28.03	0.529	0.95	0.485	-0.044	-8.28	0.74	0.451	-0.078	-14.78	0.54	0.365	-0.164	-31.04
33.70	1.33	32.35	0.547	1.13	0.523	-0.024	-4.31	0.92	0.479	-0.067	-12.33	0.71	0.444	-0.103	-18.84
27.84	1.55	37.74	0.590	1.35	0.550	-0.040	-6.84	1.14	0.527	-0.063	-10.74	0.94	0.483	-0.107	-18.21
22.07	1.78	43.13	0.631	1.57	0.593	-0.038	-5.97	1.36	0.553	-0.078	-12.37	1.16	0.530	-0.101	-16.02
17.81	2.04	49.60	0.657	1.84	0.637	-0.020	-3.01	1.63	0.605	-0.051	-7.82	1.43	0.565	-0.092	-13.97
14.72	2.31	56.07	0.686	2.10	0.663	-0.024	-3.43	1.90	0.643	-0.043	-6.31	1.69	0.617	-0.069	-10.03
11.62	2.67	64.69	0.731	2.46	0.706	-0.025	-3.43	2.25	0.679	-0.052	-7.11	2.05	0.657	-0.073	-10.06
8.61	3.07	74.40	0.753	2.86	0.743	-0.010	-1.39	2.65	0.730	-0.023	-3.08	2.45	0.704	-0.049	-6.52

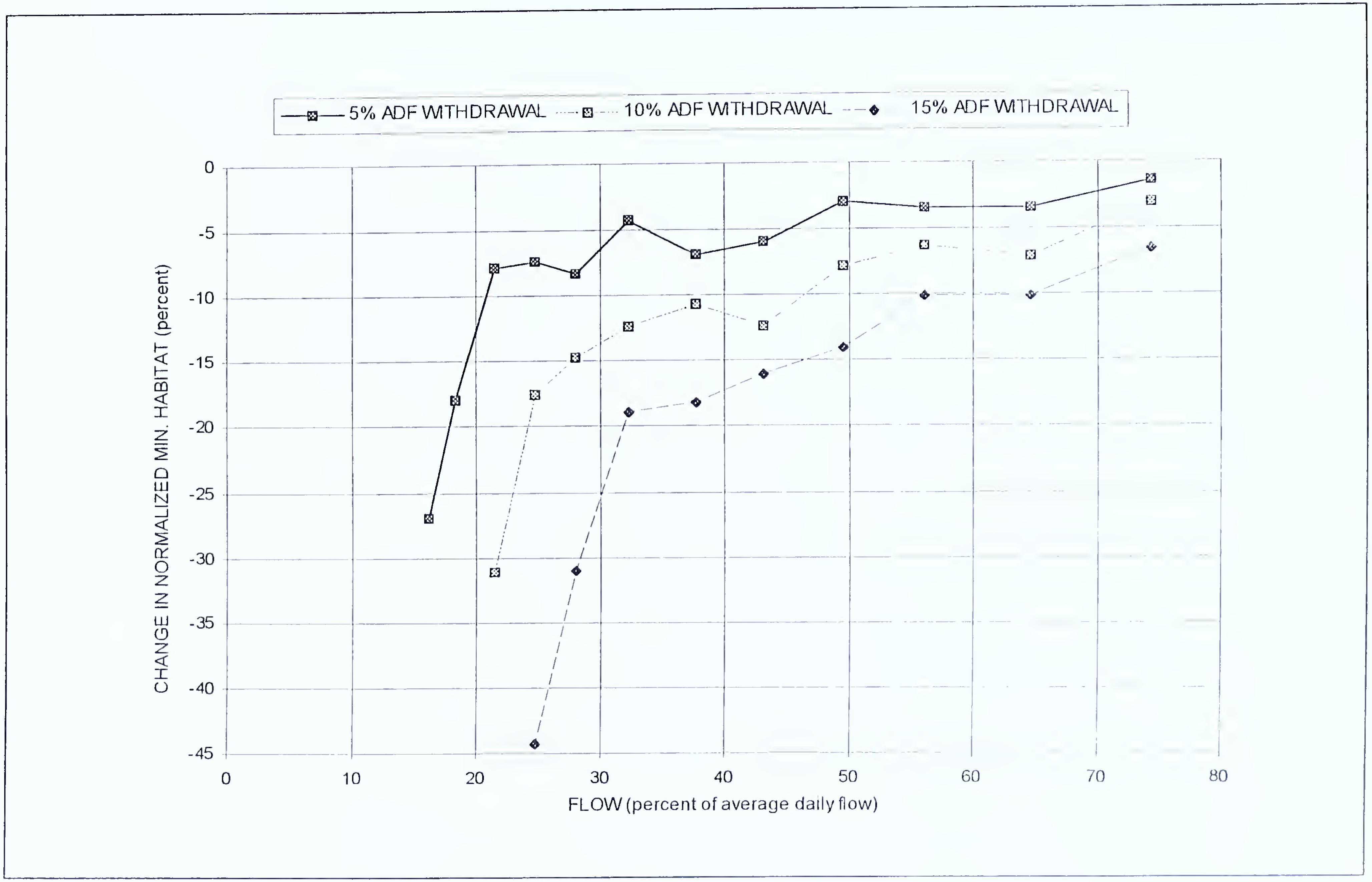

Figure 6.17. Habitat Change and Flow Relationship for Selected Withdrawals for Bear Run, Union County, Brook Trout, Summer Season

Table 6.12. Selected Points from Habitat Reduction Plot, Bear Run, Union County, Brook Trout, Summer Season

	Percentage Habitat Reduction for Selected Withdrawals		
	5	10	15
	percent ADF		
Flow at maximum impact (percent ADF)	17	22	25
Maximum impact (percent)	27	31	45
Flow at 15 percent impact	19	28	46
Flow at 25 percent impact	16	23	30

As expected, the percentage reduction decreases with increasing flow for a given level of withdrawal. The maximum percentage reduction in habitat is considerably larger than the percentage reduction in flow. The passby flows depend on the withdrawal and the level of impact, as expected. An increase in the level of reduction from 15 to 25 percent ADF decreases the passby flow by 3 to 16 percent ADF, depending on the level of withdrawal.

An example graph showing the relationship of passby flows versus level of impact for different levels of withdrawal is shown in Figure 6.18. This example shows that, for a 10 percent level of impact and a 5 percent ADF withdrawal, a passby flow equal to 20 percent of ADF is required. It also shows that, for a 5 percent ADF level of withdrawal, the passby flow requirement changes very little as the impact increases from 10 percent to 20 percent. The corresponding change in passby flow is larger for greater withdrawals. Other conclusions can be drawn from these graphs, if desired.

The flow and habitat duration impact analysis has not been completed, because of time and cost constraints. The plots of percentage reduction in habitat have been prepared for the study sites in Pennsylvania, but not for the Maryland study sites. However, analysis of the plots is incomplete.

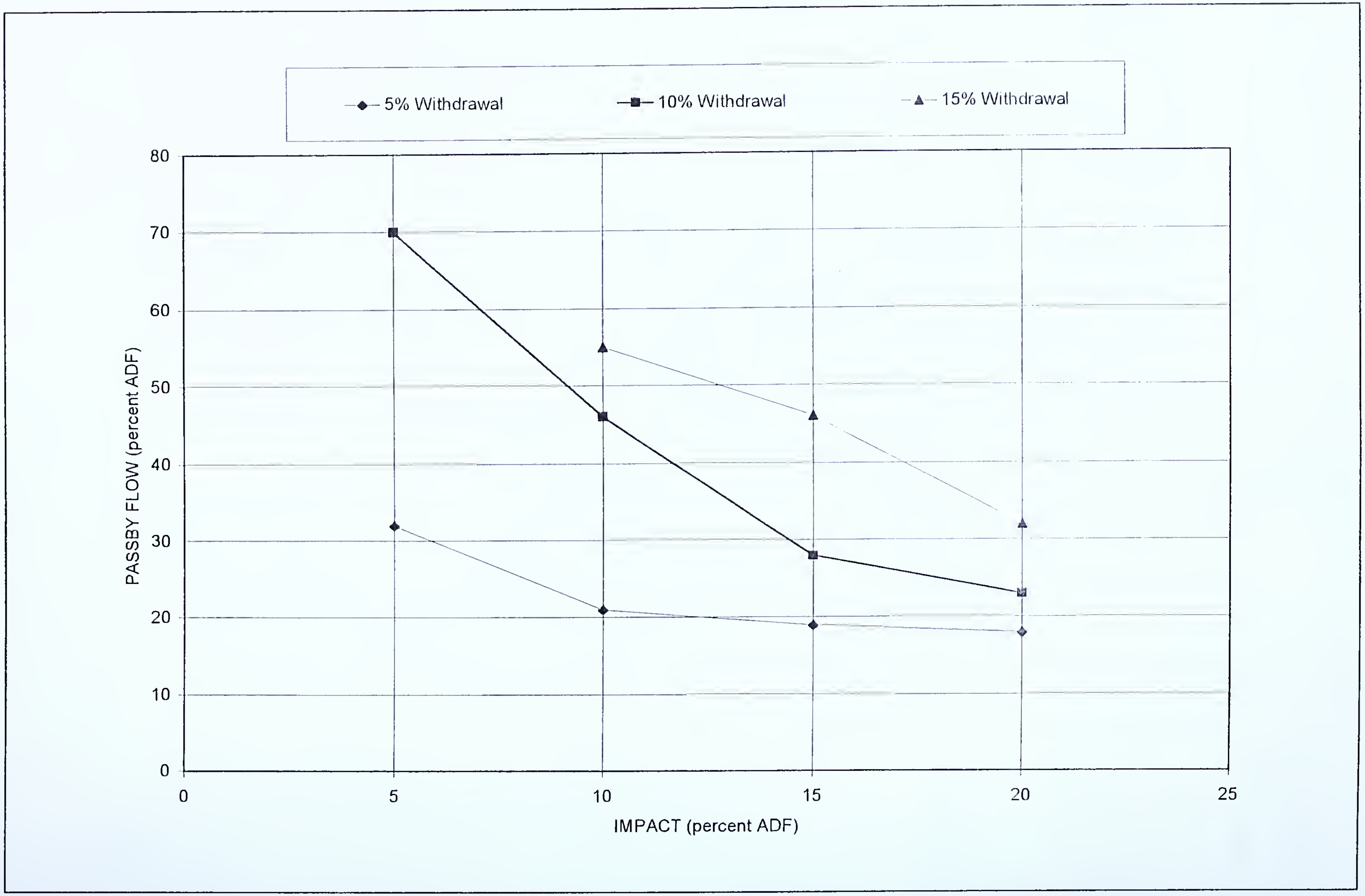

Figure 6.18. Example Passby Flow Versus Impact for Different Levels of Withdrawal, Bear Run, Brook Trout, Summer Season

7.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

7.1.1 Study purpose and methods

Existing procedures for determining mandated conservation releases from major water supply reservoirs, or mandated passby flows at smaller dams and intake structures, have certain deficiencies, as explained in section 1.0. To correct these deficiencies, Pa. DEP, SRBC, PFBC, COE, MDE, and GSBRD developed a procedure for determining instream flow protection levels that: (1) is based on fishery resource protection; (2) is clearly applicable to Pennsylvania streams; (3) does not require expensive site-specific studies; and (4) can be easily applied during the administrative review of applications for surface water allocations. The procedure is based on fishery habitat. Instream flow needs are derived from hydrologic data and the data developed in the study.

The basic approach to the problem is to conduct instream flow needs assessment studies at selected representative sites, and then regionalize the results of the site-specific assessments to develop the procedure. Because of existing critical conflicts between instream and withdrawal uses on small trout streams in the Ridge and Valley, and unglaciated parts of the Appalachian Plateaus, physiographic provinces, the study focuses on those areas. Some streams in the Piedmont Upland physiographic section in Maryland also were studied. All the study streams had naturally reproducing trout populations, with drainage areas less than 100 square miles. Therefore, the procedure applies only to those streams at this time.

The IFIM (Bovee, 1982) and the wetted perimeter method (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989) were both applied to selected streams in this study. IFIM is the most sophisticated method available for determining instream flow needs and is specifically designed to assess effects of man-made changes in flow on the habitat available for fish. The wetted perimeter method has been used by other investigators to establish instream flow protection levels.

7.1.2 Evaluation species and habitat suitability criteria

Brook and brown trout were selected as representative species for the evaluation of habitat availability and the impact of withdrawals. These species were selected because they are the most important economically and recreationally in the study regions. The periods when different life stages of these species are present were determined and used to define seasons for impact analysis.

For these species, depth and velocity suitability criteria were selected from the literature for use in the PHABSIM components of the IFIM methodology. A substrate/cover classification scheme and corresponding suitability criteria were developed for use in the study, based on professional judgement.

These suitability criteria were tested to determine whether they could be transferred to Pennsylvania. Four streams were selected for transferability testing, one brook trout stream, and one brown trout stream, in the Ridge and Valley Freestone and the Unglaciated Plateau study regions, respectively. The transferability study generally followed the methodology described by Thomas and Bovee (1993). Depth, velocity, substrate and cover were recorded at locations occupied by different life stages of the evaluation species, and at locations not occupied by fish. Statistical analyses of these data showed that the selected HSC were not suitable for use in Pennsylvania. New suitability criteria were developed using the data collected for the transferability study, and used in the subsequent PHABSIM studies.

7.1.3 Study regions and study stream selection

To develop a regional method, reproducing trout streams were classified according to key physical features that have a direct influence on the physical variables and stream attributes used to quantify fishery habitat. Streams were classified according to study region, species, and segment number.

Study regions were based on physiographic provinces and sections (Pa. DER, 1989). In the Ridge and Valley physiographic province, streams were classified into study regions based on limestone (including dolomite) or freestone (e.g., sandstone, shale, conglomerate) geology, rather than physiographic sections. In the Appalachian Plateaus physiographic province, streams were classified into glaciated and unglaciated study regions, based on the location of the glacial boundary (Pa. DEP, 1989). Streams in the unglaciated physiographic sections were combined into one study region called the Unglaciated Plateau. Trout streams in the Piedmont Province were classified based on physiographic section and limestone/freestone geology. Because of time and cost constraints, only the Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau, and Piedmont Upland (freestone) study regions were included in this study.

Parts of five counties in the southwestern corner of Pennsylvania were deleted from the study, because the streams have very low yield, and there are few reproducing trout streams in the area. For these reasons, there are few water withdrawals from reproducing trout streams in that area. The area deleted is shown in the maps in Plates 1 and 2.

Lists of streams with naturally reproducing trout populations (reproducing trout streams) in each study region in Pennsylvania were developed from existing PFBC and Pa. DEP data. The list of trout streams in Maryland was developed from a report prepared by Steinfelt (1991). The presence of reproducing trout populations on certain study streams selected in Pennsylvania was verified in the field, because the PFBC records were incomplete. Potential study streams were selected from these lists by stratified random sampling. The actual study streams were selected in the field from the list of potential streams, also using stratified random sampling.

Study streams were divided into segments based on stream length, which was used as a surrogate for stream slope. The maximum allowable length of stream segments was set at 5 miles, based on statistical analysis of stream length data. The actual segment length depended on the total length of stream.

A key assumption is that a total of 30 study segments is adequate to represent the variability in hydrology and habitat response to withdrawals in each study region. Approximately 30 segments of various sizes were studied in each of the three study regions in Pennsylvania (Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau), but only 12 segments were studied in the Piedmont Upland study region. The proportion of streams in each segment class was approximately equal to the proportion of streams in that class in the entire number of reproducing trout streams in the respective region.

7.1.4 Field data collection

Once the study streams were chosen, a representative study site was selected near the midpoint of each segment. All study sites had good access, reproducing trout populations, good water quality, and no significant human influences. Then the relative amount of each different mesohabitat type (riffle, run, pool) was estimated for each study site. A representative occurrence of each mesohabitat type was selected, and a transect was located near the midpoint of the respective mesohabitat type.

Flow rate and water surface elevation were measured at each transect, at a sufficient number of flows to allow calibration of a hydraulic model adequate to simulate flows over the range between maximum and minimum median monthly flows at each site. Velocity distribution, substrate, and cover were measured at a number of points across each transect, generally at only one flow. The measurement points were selected to represent changes in habitat or velocity across the transect. Field data collection procedures followed standard procedures (Bovee, undated: Buchanan and Somers, 1969).

Data were collected to show the location of trout redds (nests) within each mesohabitat type, to evaluate whether transects located near the midpoint of a mesohabitat type adequately represented spawning habitat. For each mesohabitat type, a large proportion of the redds was found in the central half of that type. Therefore, it was concluded that transects located near the midpoint of each mesohabitat type adequately represented spawning habitat.

7.1.5 Hydrology and habitat modeling

Hydrology was developed from flow data collected at stream gages selected to be representative of the study streams. The following hydrology was developed for the study sites:

- ADF;
- Median flow for the entire period of record;
- Median monthly flows for each month for the entire period of record;
- Time series of median monthly flows; and
- Annual and seasonal flow duration.

The hydrology for each study site was generally developed from the corresponding hydrology for a selected stream gage by multiplying flows at the gage by the ratio of drainage area at the site to drainage area at the gage. Stream gages were selected based on drainage area size, proximity to the study site, similar geology and topography, and judgment. For study streams or gages with mixed limestone and freestone geology, significant springs, withdrawals, or wastewater treatment plant flows, more complex procedures were used to derive the hydrology.

Hydraulic models, based on Manning's equation, were calibrated for each transect and measurement point at each study site. The calibrated hydraulic model was used to simulate velocity and depth for 18 flows in the range between maximum and minimum median monthly flows, in accordance with extrapolation criteria established by the Biological Resources Division of the U.S. Geological Survey . The simulated depth and velocity data were combined with the substrate and cover data, and the HSC, to develop WUA versus flow relationships for each evaluation species, life stage, and transect. The percentages of each mesohabitat type for each study site were used to compute a weighted average WUA versus flow relationship for each study site, species and life stage.

A pilot study was conducted to determine whether binary HSC should be used instead of univariate HSC, as recommended by Bovee and others (1994). WUA versus flow relationships for each type of criteria were computed and plotted. The WUA curves based on univariate criteria appeared more realistic and consistent with expected relationships for the study streams, which support good trout populations. The marginal habitat, which is not considered in the binary criteria, may be very important to trout populations. For that reason, univariate criteria were used to develop the WUA relationships used in the impact analysis.

7.1.6 Wetted perimeter analysis

Wetted perimeter versus flow plots were prepared using the output from the hydraulic simulations, for the riffle transects only. This procedure effectively assumes the inflection point occurs in the range between maximum and minimum median monthly flow. The flow rates at the inflection points of the curves were tabulated for each study region. The flow rates were converted to flow rates per unit area and to percent of ADF. These tabulations showed a lot of variability of the flow rates at the inflection points within each study region.

The plots were extrapolated to zero wetted perimeter at zero flow. The extrapolation substantially changed many graphs, and usually introduced a lower inflection point. The resulting inflection points also were tabulated for the three study regions in Pennsylvania, and are generally lower than the inflection points determined from the simulation flows alone. The conclusion is the wetted perimeter data, developed from the limited range of simulation flows, are not adequate to allow selection of inflection points. Therefore, comparisons with the results of the IFIM method are not possible without collecting additional extreme low flow data.

7.1.7 Impact assessment methods and results

The median monthly habitat was assumed to be the best measure of the amount of habitat typically available. A pilot study showed that the habitat available at the median monthly flow is essentially the same as the median of the daily habitat determined from daily flows. Therefore, the median monthly habitat was defined as the habitat value associated with the median monthly flow for subsequent analyses.

To obtain WUA versus flow relationships for each study site, each species, and each season, the life stage with the least habitat at any simulation flow was assumed to be the most critical life stage to be protected at that flow. A procedure was developed and implemented to compute these relationships, which are called the RMWUA.

To determine a conservation flow that would protect the habitat available, two alternative definitions of habitat loss were considered, no-loss of habitat, and no-net-loss of median monthly habitat. For this study, no-loss of habitat was defined as no reduction in RMWUA at any flow. No-net-loss of habitat was defined as no reduction of RMWUA at the median monthly flow. The no-loss criterion unnecessarily limits withdrawals under a wide range of conditions, considering that natural flow and available habitat fluctuate within months, and years, and among years. The no-net-loss criterion was found to significantly limit withdrawals during the summer season. Therefore, more detailed procedures were developed to assess the impact of water withdrawals on the habitat available.

The purpose of impact analysis is to determine the magnitude of the impact of withdrawals on habitat over a full range of flows, and to use that information to establish criteria for passby flows. The impact is defined as the absolute or percentage difference between habitat (RMWUA) available without the withdrawal, and the habitat available with the withdrawal in place.

Two alternative procedures were developed to estimate the impact of withdrawals on habitat. The first procedure analyzes the effect of withdrawals on time series of median-monthly flow and habitat. The second procedure analyzes the effect of withdrawals on flow and associated habitat duration.

The time series impact analysis procedure is designed to estimate the long-term effect of withdrawals for a specific project site and a specific combination of withdrawal and passby flow, using

median monthly flow time series. The method also can be used with other time steps, such as daily, but for shorter periods. The procedure estimates the average regional impact at a project site in a given stream class, of a combination of withdrawal and passby flow (both expressed as percentage of ADF) by determining impacts on each study stream in that class. Then the impacts are averaged across the study streams in that class.

A computer program has been developed in Microsoft Excel 7.0 format to estimate the impact of withdrawals for any site within a study region. There are two separate, but related, programs included in the package. The first, designated the detailed analysis program, provides a complete analysis of any combination of withdrawal and passby flow, and can analyze a number of different combinations of species and trout management procedures. This program also estimates the percent of time the withdrawal is not available for a given combination of withdrawal and passby flow. The second computer program, called the "preliminary analysis program," is designed to provide general estimates of impacts caused by withdrawals.

The detailed analysis program has been used with the hydrology and RMWUA data for selected study sites to develop habitat impact curves for the Unglaciated Plateau, Ridge and Valley Freestone, and Ridge and Valley Limestone study regions. One study site was selected for impact analysis to represent each stream gage used to develop hydrology for each segment class and study region. The data for the curves were obtained by systematically varying withdrawals and passby flows. For each segment class in each region, twenty-seven combinations of withdrawal and passby flows (e.g., 10 percent ADF withdrawal and 5 percent ADF passby flow) were run for each of the stream gages represented, and for each species variation considered. Three species were analyzed, wild brook trout, wild brown trout, and combined wild brook and brown trout.

For each study site, the average annual percent reduction in RMWUA across the period of record was used as the measure of impact. Curves of constant impact (e.g., 25 percent impact) were developed for each region, species, withdrawal, and passby flow. The Ridge and Valley Limestone region was split into two groups, based on whether the amount of limestone on the watershed was greater or less than 50 percent, and different curves were developed for each group.

Comparison of the average annual impacts for the selected study streams within each region showed little variability between the average impacts across streams and the maximum and minimum values of those average impacts. This comparison indicated that, while hydrology and stream characteristics were highly variable, habitat impacts were fairly consistent within each region. However, impacts for a given combination of species, withdrawal, and passby flow were very different among different regions. This supported the basic study concept that streams would react similarly within regions, but differently among regions.

For the Ridge and Valley Freestone study region, the impact curves for segment classes 1, 2, and 3 were close together, so these curves were averaged. Because segment class 4 included only one stream, no impact curves were provided for that class.

For the Ridge and Valley Limestone study region, the average annual impacts showed significant scatter among streams. These study sites were further classified based on the percentage of limestone in the watershed, which significantly reduced the scatter, but also reduced the sample size, especially for segment class 2, 3, and 4. Because of limited sample size and the effect of existing withdrawals, WWTP flows, and springs (or caves) on the hydrology at these study sites, impact curves were developed only for segment class 1 sites in this study region.

A partial list of limestone streams has been provided. Additional streams not included in the list should be classified as limestone or freestone, based on particular characteristics.

In the Unglaciated Plateau study region, comparison of the impact curves showed a difference between segment class 1 and 2 sites. There were no segment class 3 or 4 study sites in that region.

For all three study regions, the impact curves for brown trout and combined brown and brook trout are similar, so that either impact curve can be used. The brown trout curves are included in this report, because they are slightly more conservative. There are significant differences between impacts on brook trout, and combined brook and brown trout, as well as significant differences between impacts on brook and brown trout.

The maximum and the 90 percent probability of exceedance measures of habitat impact also were considered. The average impact curves show the long-term effect, and maximum impact curves show the short-term effect. The impact curves based on the average impact are included in this report, based on the assumption that long-term average impacts to habitat may result in average impacts to fish biomass of similar magnitude. However, since short-term maximum impacts to habitat may have more acute effects, both long-term and short-term impacts should be considered when making decisions regarding habitat protection. The impacts at the 90 percent probability of exceedance were found to be very close to the maximum impacts, and thus provided no advantage.

The constant-habitat-impact graphs also show the impact of a given passby flow on the percentage of time that a given withdrawal is not available. Obviously, the curve with the lowest habitat impact provides the greatest protection to the fishery habitat. However, as the degree of protection increases, so does the percent of time that withdrawals cannot be made because of passby requirements. The graphs show that, as the withdrawal increases to a level above 20 percent ADF, the amount of time that withdrawals cannot be made, either because of natural flow limitations, or passby requirements, or both, will be 60 to 150 days per year. Streams underlain by large amounts of limestone are exceptions because they have very substantial base flows.

These impact curves can be used to develop statewide policies regarding which impact curve(s) should be used to establish passby flows. These curves can also be used to determine impact of a proposed withdrawal at any site in these study regions. These curves also can be used by water purveyors to analyze stream intake alternatives that meet state fishery protection levels on cold water streams having drainage areas less than 100 square miles. The determination of which impact curve(s) to use will have to consider costs both to the environment and to withdrawal users.

Although regional criteria have been developed, the computer program(s) can be used to investigate alternatives or special situations that have not been considered in developing the regional criteria. Additional runs will require hydrology for the study site(s), or for a project site. A regional hydrology procedure has been developed for use in developing ADF and median monthly flow time series for any location within these study regions in Pennsylvania.

7.2 Conclusions

A procedure has been developed for determining instream flow needs and passby flows for small reproducing trout streams in Pennsylvania and Maryland. The procedure is based on available habitat, is easily derived from hydrologic records, and does not require stream-specific impact analysis studies. At present, the procedure can be applied to sites with drainage areas less than 100 square miles in the Ridge and Valley, and unglaciated parts of the Appalachian Plateaus, physiographic provinces. The procedure

includes computer program(s) that estimate the impact on fishery habitat available, resulting from various combinations of withdrawal and passby flow, for project sites in those study regions. The program also estimates the effects of imposing passby flows on the availability of water supply. This information can be used to evaluate trade-offs between impacts on fishery habitat and impacts on the water supply.

The computer program has been used to develop a set of graphs relating withdrawal, passby flow, and impact on habitat for brook, brown, and combined brook and brown trout. The impact of passby flows on water supply availability has been superimposed on the habitat impact graphs to facilitate tradeoff analysis and development of regional criteria for passby flows. The computer program(s) also may be used to study special situations not considered in development of the impact curves. The procedures can be extended to the remaining parts of Pennsylvania, Maryland, and the Susquehanna basin by collecting and analyzing additional field data for each remaining study region.

The PHABSIM components of IFIM can be applied to selected study streams to develop the WUA relationships necessary to estimate the impact of withdrawals for streams in a defined study region, and to develop regional habitat impact curves.

The computer program developed as part of this study can be used to determine the impacts of withdrawals for the study sites, and the results can be used to develop regional relationships between withdrawal, passby flow, and impact on fishery habitat. These relationships can be used to develop regional and statewide passby flow criteria.

The original concept of classifying streams based on differences in key physical characteristics that affect the availability of habitat at different flows is satisfactory for developing a regional procedure for determining instream flow needs.

The stream classification scheme, based on physiographic provinces and sections, type of geology, and stream segment number, appears to represent the differences in the key physical features that affect the availability of habitat. Also, the impact curves show that there are differences in impact between brook and brown trout, and between brook trout and combined brook and brown trout in all study regions. This result indicates that the trout species present is an important variable in determining statewide policy regarding passby flows.

The classification by segment number is useful for separating the impacts of withdrawals on small, steep streams from those that are larger and less steep. It also is useful in ensuring that streams of different size are sampled.

The impact analysis results show differences in impacts between study sites in different segment classes in all study regions. These differences are considered insignificant for the Ridge and Valley Freestone study region, and impact curves for segment classes 1, 2, and 3 were combined. Streams in the Ridge and Valley Limestone study region need to be further classified based on amount of limestone. The habitat impact curves for different segment classes behave erratically, probably due to site-specific differences in hydrology, and small sample size for segment classes 2 through 4. For the Unglaciated Plateau study region, the habitat impact curves are different for sites in segment classes 1 and 2.

7.3 Recommendations

The habitat and withdrawal impact curves developed in this study should be used by the participating agencies to develop regional or statewide procedures for determining withdrawal limits and passby flows. In particular, decisions need to be made regarding acceptable levels of impact on both uses.

This procedure also should be extended to trout streams in the Piedmont Province. Based on present knowledge, it is recommended that the province be divided into the Piedmont Upland, Piedmont Lowland, and Gettysburg-Newark Lowland sections, and that both limestone and freestone subdivisions of these sections be considered. Alternatively, the entire province could be classified as either limestone or freestone, regardless of the physiographic section.

The method should be developed for trout streams in the glaciated sections of the Appalachian Plateaus Province. Based on present knowledge, three study regions are recommended: Glaciated Low Plateau and Glaciated Pocono Plateau combined; Glaciated High Plateau; and Glaciated Pittsburgh Plateau. Also, the study design needs to consider the possibility that headwater streams formed on glacial till are much steeper and have different hydrology and habitat impact characteristics than streams formed on glacial fill materials in the valleys.

Studies of additional regions and types of streams should include evaluation of the transferability of HSC to these regions and types of streams.

It has been demonstrated that regional relationships for fishery habitat can be developed for Pennsylvania and the Susquehanna River Basin streams. It is appropriate to see if these concepts can be extended to larger cold water and warm water streams and rivers in the Susquehanna basin and Pennsylvania. These studies are needed because of existing conflicts between instream and withdrawal uses, and to facilitate evaluation of impacts of withdrawals on those streams.

The applicability of results of these studies to streams in the Ridge and Valley and Appalachian Plateaus study regions in Maryland should be considered.

7.4 Areas for Further Research

The computer program should be further refined. In particular, the hydrology calculations that are presently made externally should be incorporated in the program. Also, a reservoir operations model should be added to the program to allow consideration of minimum releases from storage facilities.

The sampling scheme utilized to select study streams and segments generally provides satisfactory results. However, the assumptions used in selecting a sample of streams should be investigated further. The number of segment class 1 study sites sampled appears to be adequate in all study regions. The number of segment-class 2 sites appears to be adequate in the Ridge and Valley Freestone and Unglaciated Plateau study regions, but appears inadequate in the Ridge and Valley Limestone study region. The number of segment-class 3 and 4 sites appears to be inadequate in all study regions. There may be a need for additional segment class 3 and 4 study sites in all study regions, and additional segment class 2 sites in the Ridge and Valley Limestone region. Also, the relationship of the stream selection procedures to variations in hydrology within a study region should be evaluated to determine whether each hydrologic region should be sampled. Variations in hydrology among segment classes due to both natural and man-made conditions, also should be considered.

Transects located near the midpoint of each mesohabitat type appear to provide satisfactory sampling of spawning habitat. In future studies, it may be desirable to collect data at a transect in the tail of pools to include the area with the highest proportion of redds.

The field measurement and model calibration problems encountered in this study should be considered and minimized in selecting streams for future studies.

The HSC developed in this study are based on the best field data obtainable with the resources available for the study. However, these criteria could be refined in future studies by: testing the HSC developed in this study against independent habitat usability data for streams in the same study regions; developing separate HSC for each study region; developing HSC for rainbow trout; or collecting additional data to allow evaluation of the effects of season, time of day, or other trout species present. Development of habitat suitability criteria for rainbow trout allows application of the procedures, including habitat impact curve development, to that species.

The regional hydrology procedures developed in this study are the best that could be developed within the time and cost constraints of the study. As experience is gained with the procedures, refinements may become necessary or desirable.

The habitat data for the Maryland study streams should be used cautiously, because of evidence that some of the streams are not in dynamic equilibrium. The existing data should be verified through other sources, or collection of additional data. Also, the effect of changes in bed and banks on habitat estimation should be evaluated.

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GLOSSARY

A

ADAPS — USGS computerized water data file.

Adult life stage — Trout 6 or more inches long.

Alpha — Used in statistical tests as the probability of incorrectly rejecting the hypothesis that the data come from an assumed relationship.

Average daily flow — The arithmetic mean of individual daily mean discharges during a period of record.

ADF — Average daily flow.

Associated habitat duration analysis — Development of habitat probability relationship by determining habitat corresponding to a flow and assigning the probability of the flow to the habitat.

B

Binary suitability criteria — Habitat suitability criteria that have values only of zero or unity.

C

Calibration flow — Flow at which satisfactory field measurements have been made, and used to calibrate hydraulic model(s).

CDS — Complete data set.

Channel — The groove through which water of a stream normally flows.

Chi-square test — A statistical method for determining whether observations fit an assumed probability distribution.

Complete data set — A data set collected at a study site, preferably in the range necessary to allow extrapolation to the highest flow necessary to be modeled; generally includes bottom and overbank survey, velocity and depth measurements at each measurement point, water surface elevation and substrate/cover determination for each transect at that site, and flow rate computation.

Conservation flow — Mandated flow expected to be maintained downstream from a water storage facility or water intake to protect instream uses, including fishery habitat.

Conservation releases	Releases made from a controlled water storage facility to maintain some amount of flow in the stream downstream from the facility.
Consumptive use	Loss of water from ground-water or surface water source, through a man-made conveyance system, by a process that does not return the water to the basin.
Cover	Areas of shelter that provide resting places, visual isolation, or protection from predators for aquatic organisms.
cfs	Cubic foot per second.
csm	Streamflow rate per unit of drainage area, cubic feet per second per square mile.
Cross section	Same as transect.
Cubic foot per second	Unit of measurement of flow of a stream.
Current meter	A device used to measure the velocity of water in a body of water.

D

Daily flow	Average of instantaneous discharges during a clock day.
Duration analysis	Categorization of events (e.g., flow rates or habitat available) to determine the probability of exceedance by arranging the values in order of magnitude.
Detailed analysis program	Computer program written in Microsoft Excel format for complete analysis of the impact of any combination of withdrawal and passby flows on the flow and habitat of a project stream; see preliminary analysis program.
Diversion	Withdrawal from a body of water by man-made conveyance system.

E

Ecoregion	An area expected to have similar ecological characteristics (Omernik, 1987a, b).
Electrofishing	Sampling fish populations by temporarily stunning them with an electrical current.
Exceptional Value Waters	A stream or watershed that constitutes an outstanding national, state, regional or local resource...of substantial recreation or ecological significance (Pennsylvania Code, Title 25, ch. 93, pp. 93-8).

Evaluation species	Species used to estimate effects of changes in flow on the aquatic ecosystem.

F

Fall season	Months of October through February when adult, juvenile, and spawning life stages are present.
Flow duration analysis	Duration analysis of streamflow data of a selected time step (e.g., daily or monthly).
Freestone	A general term for the class of rocks that do not contain significant amounts of carbonate minerals. See limestone.
Freestone streams	Streams that drain areas underlain by noncarbonate rocks; defined in this study as streams not meeting the criteria to be considered as limestone streams. See limestone streams.
Flow protection	Maintenance of flows to prevent significant reductions in habitat for aquatic species, or other instream uses.
Fry life stage	Immature fish after emergence from gravel, assumed herein to be less than 2 inches long.

G

Gaging station	Point on a stream or water body where water surface elevations or flow are systematically measured.
Glacial boundary	Location of the terminal moraine of the late Wisconsin glacial advance, as defined by Sevon (1995).

H

Habitat	The place where an organism or population lives and its surroundings, both living and nonliving; used herein to refer to the physical aspects of habitat represented as weighted usable area.
Habitat suitability criteria	Relationship(s) describing usability of different values of physical habitat variable(s) (depth, velocity, substrate/cover) that compose the physical habitat of species.
High Quality Waters	A stream or watershed that has excellent quality waters and environmental or other features that require special water quality protection (Pennsylvania Code, Title 25, ch. 93, pp. 93-8).

HSC	Habitat suitability criteria.
Hydrologic region	A portion of a study region assumed to be hydrologically similar for computing ADF and median monthly flows for project streams.
Habitat duration	Duration analysis of habitat data of selected time step (e.g., daily or monthly).

I

Impact	Absolute or percentage difference between the amount of habitat available without the withdrawal and the amount available with the withdrawal.
Instream use	Any use of water that does not require diversion or withdrawal from the natural watercourse.
Instream Flow Incremental Methodology	A method to quantify the effects of alterations of streamflow on the aquatic ecosystem.
IFIM	Instream Flow Incremental Methodology.
Inflection point	Point where the slope of a curve changes.
Invertebrate	Animal that has no backbone; used herein to refer to aquatic insects.

J

Juvenile life stage	Immature fish larger than fry; assumed herein to be between 2 and 6 inches long.

L

Life stage	An arbitrary age classification of an organism used in this study to describe adult, juvenile, fry and spawning periods in the life of selected species.
Limestone	A general term for the class of rocks that contain carbonate minerals (calcium carbonate or magnesium carbonate), as shown by Pa. DER (1990).
Limestone streams	Streams draining areas underlain by carbonate rocks; defined in this study as streams having total alkalinity greater than 70 mg/l, or identified as limestone streams by Shaffer (1991).

M

Median monthly flow	Median value of all the daily flows during a particular month for some period-of-record.
Median monthly habitat	Habitat available half the time during a particular month in the record; defined in this study as habitat available at the median monthly flow.
Mesohabitat	Collective term for different stream habitat types (e.g., riffle, run, pool).
Microhabitat	Small localized areas within a mesohabitat type, typically described by a combination of depth, velocity, substrate, or cover.
Morphology	The form and structure of a watershed, stream channel, or biological community.
Modified forage index	An electivity index used to measure the degree of preference for various microhabitat conditions.

N

No-loss of habitat	No reduction of weighted usable area at any flow.
No-net-loss of habitat	No reduction in weighted usable area at the median monthly flow.
No-net-loss flow	The flow that results in no-net-loss of habitat, computed as the smaller of the flow at the maximum renormalized minimum weighted usable area and the median monthly flow.
Normalized Modified Forage Index	Modified forage index scaled to a range from zero to one; used to develop habitat suitability criteria.
NMFI	Normalized modified forage index.

P

Partial data set	A data set collected at a study site, at an appropriate flow, for model calibration; generally includes at least flow rate and water surface elevation measurements for each transect at that site.
Passby flow	The flow rate below which a withdrawal can not be allowed.
Periodicity	Time of occurrence of different life stages during the year.
PDS	Partial data set.

PHABSIM	Physical Habitat Simulation Program; a set of software and methods used to compute relationships between physical habitat and streamflow.
Physiographic province	Region with similar structural characteristics and a unified geomorphic history, as described by Fenneman (1938) and delineated by Pa. DER (1989) and Sevon (1995).
Physiographic section	A subdivision of a physiographic province, as delineated by Pa. DER (1989), Sevon (1995), or Sevon (in preparation).
Pool	Part of a stream where velocity is reduced, usually with deeper water than surrounding areas.
Preliminary analysis program	Computer program written in Microsoft Excel format for initial analysis of the impact of combinations of withdrawal and pre-specified passby flows on the flow and habitat of a project stream; see detailed analysis program.
Project stream	Stream where the impact of a proposed withdrawal is to be evaluated.
Protection	Maintenance or protection of habitat.

Q

$Q_{7\text{-}10}$	Seven-day, ten-year low flow.

R

Reach	Any defined length of a river or stream.
Redd	A depression in the streambed created by trout or salmon for spawning purposes.
Renormalized minimum weighted usable area	The amount of weighted usable area available for the most limited life stage at each flow, rescaled to a range of zero to unity.
Reproducing trout stream	Stream with naturally reproducing trout population(s).
Riffle	Shallow rapids in a stream where obstructions create waves.
RMWUA	Renormalized minimum weighted usable area.
Run	A part of a stream characterized by rapid velocity and few waves over a significant length.

S

Season	Period of time when the same life stages are present.
Segment	A certain length of a study stream.
Seven-day, ten-year low flow	The smallest flow in a period of seven consecutive days expected to occur, on the average, once every ten years at a particular location along a stream.
Simulation flow	Any flow rate for which depth, velocity and weighted usable area have been computed.
Spawning life stage	Life stage defined herein as including redd construction, laying and incubation of eggs, and immature trout up to the time of emergence from the substrate in the spring of the year.
Spring season	Months of March through June, when adult, juvenile, and fry life stages are present.
Study region	A part of a physiographic province or section assumed to have homogeneous topographic, geologic, hydrologic, and habitat characteristics.
Study site	A representative portion of a study segment selected for detailed data collection and modeling.
Study stream	A stream selected from lists of trout streams and assumed to be representative of other trout streams in the same study region.
Substrate	The material on the bottom of the stream channel such as rocks, gravel, or sand.
Summer season	Months of July through September, when only adult and juvenile life stages are present.

T

Time series	A set of values arranged in chronological order.
Transect	A vertical cross section taken across the stream.

U

Univariate suitability criteria	Habitat suitability criteria that vary continuously over the range from zero to unity.

Unit flow rate (csm)	Flow rate per unit drainage area, cubic feet per second per square mile.

W

Weighted usable area	Unit of measurement of habitat used in Instream Flow Incremental Methodology; the wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity (units of square feet per thousand feet of stream).
Wetted perimeter	The length along the bottom and sides of a stream channel, perpendicular to the flow, that is in contact with the water at a particular flow rate.
Wetted perimeter method	A method for determining flows that maintain the availability of food based on the relationship of wetted perimeter to flow.
WUA	Weighted usable area.
WWTP	Wastewater treatment plant.

Appendix A

Field Manual
Habitat Suitability Curve Transferability Testing for Pennsylvania Instream Flow Incremental Methodology Studies

A1.0 INTRODUCTION

The purpose of this study is to determine whether existing habitat suitability criteria (HSC) for brook trout and brown trout adults, juveniles, fry, and spawning are transferable to Pennsylvania Streams with wild trout populations and drainage areas of less than 100 square miles.

Bovee (1982) emphasizes that selection of the appropriate evaluation species for studies using the Instream Flow Incremental Methodology (IFIM) is important because all interpretations of environmental impacts hinge on the effect on the evaluation species. Habitat suitability criteria are used in the Physical Habitat Simulation System (PHABSIM) to evaluate effects on habitat for the evaluation species.

The work group of the Susquehanna River Basin Commission's (SRBC's) Instream Flow Subcommittee originally considered brook trout, brown trout, white sucker, blacknose dace, and slimy sculpin as possible evaluation species. Brook and brown trout were selected because they are the most recreationally and economically important species in the study streams. White sucker, blacknose dace, and slimy sculpin were originally considered because they can serve as forage species for trout. However, white sucker adults are tolerant of a variety of flow conditions and are not generally abundant in the smaller headwater trout streams. Only a limited number of HSC have been developed for blacknose dace and slimy sculpin. In light of the above, the work group has decided to focus only on brook and brown trout as evaluation species.

Work group representatives from the SRBC and PFBC reviewed existing brook and brown trout HSC for possible transferability testing. HSC examined included those that were cited by Raleigh and others (1986), Aceituno and others. (1985), Harris and others (1992), Jirka and Homa (1990), Normandeau Associates Inc. (1992), Bovee (1994), and Whelan (1994).

Combined HSC for brook and brown trout will be used for transferability testing. Testing will be performed on depth and mean column velocity HSC for fry, juveniles, and adults that were cited by Normandeau Associates Inc. (1992) and on Whelan's (1994) depth and mean column velocity HSC for spawning. Substrate and cover HSC for all life stages were developed by PFBC and SRBC staff for transferability testing. Nose velocity HSC are not being used for the Pennsylvania IFIM studies and will not be considered for transferability testing.

A2.0 SELECTION OF STREAMS FOR TRANSFERABILITY TESTING

Lanka and others (1987) cited that trout stream habitat in the Rocky Mountains is greatly influenced by drainage basin geomorphology. Similarly, Nelson and others (1992) found that trout distribution in the North Fork Humboldt River drainage area of northeastern Nevada is related to geologic district and land type association.

The physical and biological characteristics of wild trout streams vary greatly among physiographic regions in Pennsylvania, as well as between limestone and freestone streams. No one stream could be selected that contains all habitat types found in wild brook and brown trout streams in the Commonwealth. For this reason, transferability studies were planned to be performed on one stream from each of the following categories:

- Ridge and Valley Physiographic Region, limestone wild brown trout stream
- Ridge and Valley Physiographic Region, freestone wild brown trout stream
- Ridge and Valley Physiographic Region, freestone wild brook trout stream
- Unglaciated Plateau Physiographic Region, wild brown trout stream
- Unglaciated Plateau Physiographic Region, wild brook trout stream

Note: No limestone wild brook trout streams were identified in the Ridge and Valley Physiographic Region.

Commission staff questions whether the HSC will be transferable to all of the streams listed above. Without performing transferability studies on a variety of streams, this important question can not be answered.

To the extent possible, transferability testing will be performed on larger streams that have a drainage area of less than 100 square miles, large numbers of wild trout, excellent water quality and visibility, and good structural and hydraulic diversity. To facilitate trout identification during sampling, an attempt was made to select streams that did not contain significant numbers of more than one trout species.

SRBC and PFBC staff performed reconnaissance electrofishing on potential streams for transferability studies during May and June 1994. Based on the electrofishing results, the following streams were selected for transferability studies:

- Elk Creek, Centre County (Ridge and Valley Physiographic Region, limestone wild brown trout)
- Cherry Run, Centre and Union Counties (Ridge and Valley Physiographic Region, freestone wild brown trout)
- Little Fishing Creek, Centre County (Ridge and Valley Physiographic Region, freestone wild brook trout)
- Young Womans Creek, Clinton County (Unglaciated Plateau Physiographic Region, wild brown trout)
- Whitehead Run, Cameron County (Unglaciated Plateau Physiographic Region, wild brook trout)

Based on budget limitations, the Instream Flow Subcommittee Work Group decided in July 1994 to defer the proposed work on Elk Creek.

All of the selected streams have sections that are classified by the PFBC as 1994 Class A Wild Trout Waters. Electrofishing results indicate that brown trout are abundant in Elk Creek, Cherry Run, and Young Womans Creek. Brook trout are abundant in the study areas on Little Fishing Creek and Whitehead Run. Fry, juveniles, and adults were identified in all of the selected streams.

Commission staff believes that Elk Creek, Little Fishing Creek, and Young Womans Creek can be sampled using the combination of surface observations, underwater observations with snorkel diving gear, and electrofishing described below. Elk Creek and Young Womans Creek are larger streams where snorkel diving will be extensively used as a sampling technique. Because of its small size (8-10 feet wide), Little Fishing Creek will be sampled primarily by using surface observations and electrofishing equipment. However, snorkel observations may be possible in some locations in Little Fishing Creek. Cherry Run and Whitehead Run are small streams where surface observations and electrofishing will be the primary sampling methods.

Several other streams were sampled with electrofishing gear before Commission staff selected the five streams listed above. Possible alternative ridge and valley physiographic region. freestone wild brown trout streams that were sampled by Commission staff included Lost Creek in Juniata County, Wallace Run in Centre County, Swift Run in Mifflin County, Laurel Run in Union County, and the Lackawanna River in Lackawanna County.

Lost Creek was sampled on June 9, 1994, and was found to have excellent habitat diversity and water clarity. Although the stream contained good numbers of adult brown trout, relatively few juveniles and fry could be found. The stream also contained significant numbers of adult brook trout.

Wallace Run and Swift Run were sampled on June 20, 1994. Both streams were found to contain mixed populations of brook and brown trout. The ratio of brown trout to brook trout was about 60/40 in Wallace Run and about 50/50 in Swift Run. Wallace Run was found to have few fish.

Laurel Run was sampled on June 22, 1994, and found to have mixed populations of brook and brown trout. Extensive streambank shading made fish observations difficult.

The Lackawanna River near Archbald, Pa., was sampled on June 23, 1994. In this area, the stream is large enough to be sampled with snorkel gear and has good habitat diversity. However, the stream contained much trash and household debris, raising concerns for diver health and safety. The stream was found to contain mixed populations of brook, brown, and rainbow trout.

After considering the alternative streams listed above, Commission staff selected Cherry Run as the Ridge and Valley Physiographic Region, freestone wild brown trout stream for HSC transferability testing.

Reconnaissance electrofishing was performed on several streams before the wild brook trout study stream in the Unglaciated Plateau Physiographic Region could be selected. John Summerson Branch and Trout Run in Clinton County were sampled on May 19, 1994, but did not contain adequate numbers of trout for HSC transferability testing. Sampling in John Summerson Branch was performed near the mouth. Further discussion with the PFBC's area fishery manager indicated that trout are more abundant upstream. Accessibility to upstream areas of John Summerson Branch is a problem because the one dirt road to the area leads only to the mouth of the stream. Any further travel to upstream areas would have to be on foot.

On June 21, 1994, Commission staff sampled Grove Run in Cameron County, Montour Run in Clinton and Cameron Counties, and Whitehead Run in Cameron County. At the time of sampling, Grove Run contained good numbers of brook trout, but also contained many brown trout. Montour Run did not contain sufficient numbers of brook trout for HSC transferability testing. Sampling on Whitehead Run indicated that the stream has an excellent population of brook trout, is easily accessible, and has good habitat diversity and water clarity. Only a few isolated brown trout were identified during electrofishing activities. In light of the above, Whitehead Run was selected as the unglaciated plateau physiographic region, wild brook trout stream for HSC transferability testing.

A3.0 FIELD SAMPLING PROCEDURES

Commission staff will conduct the transferability studies using the general methodology described by Thomas and Bovee (1993). Microhabitat measurements will be taken at locations where undisturbed

fish are observed and in randomly selected locations where fish are absent. Field data will be used to conduct a one-sided chi-square test to determine whether the HSC are transferable to the study streams.

The effectiveness of snorkel diving to make direct observations of undisturbed fish has been well documented (Bovee, 1986; Bovee and Zuboy, 1988). For this reason, snorkel diving will be used to the maximum extent possible in making fish observations for the transferability studies. However, not all habitat in Pennsylvania streams can be sampled using this method. A significant portion of the area in most wild brook trout streams and some wild brown trout streams is either too shallow to float a diver or difficult for a diver to approach without disturbing fish. For habitat types than cannot be effectively sampled with snorkel gear, surface observations and electrofishing will be used to identify fish locations.

For the purpose of this investigation, fry will be considered to be fish less than 2 inches in total length, juveniles to be 2 to 6 inches in total length, and adults to be 6 inches or more in total length. Spawning locations will be identified either by the presence of spawning fish or a redd. A plastic ruler will be carried by fish observers to assist in estimating length.

A minimum of four sampling trips will be made to each of the study streams during the course of a one-year period. The appropriate PFBC law enforcement regional office (Appendix A1) will be informed at least 24 hours in advance of each sampling trip as required under the SRBC's scientific collection permits.

Each trip to each stream is expected to require an average of one week of sampling effort. Life stages sampled during each of the four trips will be as follows:

- Adults and juveniles
- Adults and juveniles (different flow level than first sampling)
- Spawning (anticipated spawning in October for brook trout, November for brown trout)
- Fry (spring or early summer)

The two sampling trips for adults and juveniles are scheduled for July-August 1994. Sampling will not be performed during extreme low flows when habitat diversity is limited, or during extreme high flows when observations are difficult or dangerous. Depending on streamflow conditions, some of the sampling trips may need to be performed at a later date. In order to perform the required statistical analyses, microhabitat measurements for each trip and life stage will be made at 55 or more occupied locations and 200 or more unoccupied locations. A flow measurement at the downstream end of the sampling area will be taken on the first day of each sampling trip.

During the development of this field manual, a concern was raised that it may not be possible to identify the locations of 55 fish that are at least 6 inches long during each of the times that adult and juvenile brook trout are sampled at Little Fishing Creek and Whitehead Run. Growth rates vary from stream to stream, and brook trout in small streams such as these may be sexually mature before they are 6 inches long.

Bovee (1986) indicates that size class is a preferred means of HSC stratification because it is a more precise measurement than life stage or age group. If it is not possible to identify the locations of 55 fish that are 6 inches long during the full week of sampling and it is apparent from the data that a distinction can be made between adults and juveniles based on a length less than 6 inches, this lesser length will be noted and considered for the breakdown between juveniles and adults. The rationale for this modified breakdown will be documented in the trip notes prepared by the sampling team leader. This

modified breakdown using the lesser length will only be considered as a last resort if 55 observations can not be made of fish that are at least 6 inches long. Every reasonable effort will be made to identify the locations of as many fish as possible that are at least 6 inches long.

Equal areas of all mesohabitat types will be sampled, regardless of which mesohabitat types are most abundant or have the greatest concentrations of fish. The locations of all undisturbed fish at each mesohabitat sampling site will be marked and appropriate data will be recorded. For example, if a stream has six mesohabitat types, equal areas of all six mesohabitat types will be sampled. If 55 occupied locations are identified in the first mesohabitat type sampled, equal areas of the remaining five mesohabitat types will still need to be sampled and microhabitat measurements will need to be recorded for occupied locations.

If two (non-spawning) fish are located within one foot of each other, they will be considered to be in the same location (IFIM cell) if all microhabitat measurement values are equal. If any one measurement (depth, velocity, substrate, or cover) is different, the fish will be considered to be in separate occupied locations.

The 200 or more unoccupied sampling locations will be distributed equally among all mesohabitat types. In the above example, at least 34 unoccupied locations would be sampled in each of the six mesohabitat types.

The appropriate equipment listed on Appendix A2 will be included on each field sampling trip. Electrofishing gear will only be needed to identify juvenile, adult, and fry locations and will not be used when making spawning observations.

Sampling will be performed by a three-man crew as specified below. The crew leader and at least one other crew member will be trained in cardiopulmonary resuscitation (CPR).

During field observations, a conscious effort will be made to avoid fish fright and investigator bias. Surface observation will be the first sampling method used to locate fish at each mesohabitat sampling site. The observer will wear camouflage clothing and the approach to the site will be made by moving in an upstream direction. If possible, the approach and observations will be made from the bank, using any available cover for the approach. Care will be taken not to cast shadows on the portion of stream to be sampled. Care also will be taken not to frighten fish into the sample site from either downstream or upstream areas. Observations will be made with the aid of polarized sunglasses and a pair of binoculars.

The observer will mark each fish location with a lead fishing sinker marked with a numbered piece of plastic surveyor's tape. The date, time, mesohabitat type, observation technique, marker tag number, fish species, length, and life stage will be entered on a copy of the data sheet shown as Appendix A3.

If the mesohabitat sampling site that was marked as per the above can also be sampled with snorkel gear, a nylon rope may be stretched through the length of the sampling site to assist the diver in moving upstream. This may be done with minimal disturbance to fish by fastening one end of the rope to an upstream anchor (rock, log, etc.) and attaching the other end of the rope to the handle of a plastic jug that is partially filled with water and floated downstream to the end of the sampling site.

Underwater observations will be made by a diver equipped with the snorkel sampling gear listed in Appendix A2. If fish were disturbed by the surface observations and setup procedures described above, at least one half hour will be allowed to pass before snorkel observations are begun.

The diver will carefully approach the downstream end of the sample site and move upstream in a zigzag fashion, sampling all habitat from bank to bank. When an undisturbed fish is observed, the diver will mark its location with a marker as described above. After each marker is positioned, the diver will roll his head out of the water and report the tag number, species, length, and life stage to an assistant on the bank of the stream. The assistant will enter the information on the same data sheet used for surface observations and also will record the date, time, mesohabitat type, and observation technique.

Using polarized sunglasses, the data recorder will also note any fish that are disturbed by the diver to ensure that their locations are not inadvertently counted. The data recorder also will assist the diver in site setup and equipment transport and will serve as the diver's "buddy" for safety purposes.

If the mesohabitat sampling site that was marked using surface observations can not be sampled with snorkel gear, electrofishing will also be used to identify the locations of undisturbed fish. Precautions will be made to avoid fright bias as described for surface observations. As with snorkel observations, electrofishing will be performed in a systematic manner, sampling at points from downstream to upstream and from bank to bank.

Electrofishing will be performed with a backpack DC shocker and two hand-held electrodes. For each point sampled, the electrodes will be carefully positioned and the current will then be switched on and the locations of fish identified. Fish will be netted with a dipnet or minnow seine if necessary for identification or measurement. Handling will be minimal and all fish will be safely returned to the water. Fish locations will be marked as described previously and appropriate notations will be made on the same data sheet used for surface observations.

After fish locations have been marked, the third crew member will measure and record water depth to the nearest 100th of a foot using a top setting rod equipped with a current meter. Water temperature in degrees centigrade at the fish location will also be measured and recorded. The number of cup rotations per unit of time (at least 40 seconds) will be recorded on the data sheet so that mean current velocity for each location can be calculated. If the water depth is less than 2.5 feet, one current meter reading will be taken at six tenths of the distance from the water surface to the stream bottom. If the water depth is greater than 2.5 feet, one current meter reading will be taken at two tenths and another reading will be taken at eight tenths of the distance from the water surface to the stream bottom. (The top setting rod is directly calibrated for setting the meter six tenths of the distance from the water surface to the stream bottom, but must be manually set for two tenths and eight tenths of the distance.) Mean column velocity will be calculated to the nearest 100th of a foot per second.

Before removing the fish location markers from the stream bottom, a random sampling procedure will be used to select locations that were unoccupied by fish. After measuring the width and length of the mesohabitat area sampled, the tape used for making the measurement will be left stretched in or along the length of the stream. A random number table will then be used to determine the distance that the first unoccupied location will be located from the downstream end of the sampling area. A die will then be rolled to determine the distance across the stream to sample. If a "1", "2", "3", "4", or "5" is rolled, sampling will be conducted 1/6, 2/6, 3/6, 4/6, or 5/6 of the distance from the left side of the stream to the right side when facing upstream. If a "6" is rolled, a second roll of the die will be made. If the number on this second roll is even, sampling will be performed along the right bank; if the number is odd, sampling will be performed along the left bank when facing upstream.

Additional unoccupied locations will be selected using the same methodology described above. Unoccupied locations will not be selected within one foot of an occupied location. Data will be collected and recorded on a copy of the field data sheet for unoccupied locations shown in Appendix A4.

For each field sampling trip, the field crew leader will prepare trip notes using the form shown in Appendix A5.

Field data sheets and trip notes will be submitted to the transferability study coordinator (Dave Heicher), who will perform one-sided chi-square tests described by Thomas and Bovee (1993) to determine HSC transferability.

Appendix A1

Pennsylvania Fish and Boat Commission Law Enforcement Regional Offices

Pennsylvania Fish and Boat Commission Law Enforcement Regional Offices

Northwest Region: P.O. Box 349, 1281 Otter Street, Franklin, PA 16323. (814) 437-5774

Butler, Clarion, Crawford, Erie, Forest, Lawrence, Mercer, Venango and Warren Counties

Southwest Region: R.R. #2, Box 39, Somerset, PA 15501-9311. (814) 445-8974

Allegheny, Armstrong, Beaver, Cambria, Fayette, Green, Indiana, Somerset, Washington and Westmoreland Counties

Northeast Region: P.O. Box 88, Sweet Valley, PA 18656. (717) 477-5717

Bradford, Carbon, Columbia, Lackawanna, Luzerne, Monroe, Montour, Northumberland, Pike, Sullivan, Susquehanna, Wayne and Wyoming Counties

Southeast Region: P.O. Box 8, Elm, PA 17521. (717) 626-0228

Berks, Bucks, Chester, Delaware, Lancaster, Lehigh, Montgomery, Northampton, Philadelphia and Schuylkill Counties

Northcentral Region: P.O. Box 187 (Fishing Creek Rd.), Lamar, PA 16848. (717) 726-6056

Cameron, Centre, Clearfield, Clinton, Elk, Jefferson, Lycoming, McKean, Northumberland, Potter, Snyder, Tioga and Union Counties

Southcentral Region: 1704 Pine Rd., Newville, PA 17241 (717) 486-7087

Adams, Bedford, Blair, Cumberland, Dauphin, Franklin, Fulton, Huntingdon, Juniata, Lebanon, Mifflin, Northumberland, Perry and York Counties

Appendix A2

List of Equipment for IFIM Transferability Studies

List of Equipment for IFIM Transferability Studies

Surface Observations
polarized sunglasses
camouflage clothing
binoculars
6-inch plastic ruler

Underwater Observations with Snorkel Gear
mask with corrective lenses, if necessary
snorkel
two-piece, semi-dry diving suit
neoprene gloves and boots
wading shoes
two 100-ft nylon ropes
fishing sinkers
indelible marker
plastic surveyor's ribbon
mesh bag
plastic jug

Electrofishing
backpack DC shocker with probes
gasoline mixed with oil
hand-held collection net
4 ft. X 4 ft. seine
hip boots
chest-high waders

Microhabitat Measurements and Other
top-setting rod
measuring rod for depths greater than can be measured with top-setting rod
Price AA current meter
Pygmy current meter
stopwatch or wristwatch with stop mode
100 ft. cloth or fiberglass tape
field data sheets
topographic quads and location maps
thermometer marked in degrees centigrade
random number table
die

Appendix A3

Field Data Sheet for Occupied Locations, IFIM Transferability Studies

Field Data Sheet for Occupied Locations, IFIM Transferability Studies

Stream Name:	Crew Members:
	Type of Flow Meter:

Observation Number	Date	Time	Mesohabitat Type	Observation Technique	Tag No.	Sp.	Length (inches)	Life Stage	Depth (ft)	Rotations/ Seconds	Velocity (ft/sec.)	Temp. (°C)	Substrate	Cover

Field Data Sheet for Occupied Locations, IFIM Transferability Studies—Continued

Observation Number	Date	Time	Mesohabitat Type	Observation Technique	Tag No.	Sp.	Length (inches)	Life Stage	Depth (ft)	Rotations/ Seconds	Velocity (ft/sec.)	Temp. (°C)	Substrate	Cove

CODES FOR FILLING IN DATA SHEET

Species

BK = Brook trout

BN = Brown trout

Mesohabitat Type (code & description to be filled in after preliminary field evaluation)

1 ____________________

2 ____________________

3 ____________________

4 ____________________

5 ____________________

6 ____________________

7 ____________________

8 ____________________

9 ____________________

10 ____________________

Life Stage

AD = Adult (6 inches or more)

JU = Juvenile (2 to 6 inches)

FR = Fry (less than 2 inches)

SP = Spawning fish

RD = Redd

Observation Technique

SU = Surface observation

UN = Underwater observation (snorkel)

EL = Electrofishing

Substrate

1 = Diameter of < 3 mm (silt, sand)

2 = Diameter of 3 mm - 64 mm

3 = Diameter of > 64 mm

Cover

1 = No cover

2 = Object at least 6 inches high and with a cross section horizontal measurement of at least 1 ft

3 = Undercut object along bank

4 = Aquatic vegetation

5 = Terrestrial vegetation < 1 ft high

Appendix A4

Field Data Sheet for Unoccupied Locations, IFIM Transferability Studies

Field Data Sheet for Unoccupied Locations, IFIM Transferability Studies

Stream Name:	Crew Members:
	Type of Flow Meter:

Observation Number	Date	Time	Mesohabitat Type	Depth (ft)	Rotations/ Seconds	Velocity (ft/sec.)	Temp. (°C)	Substrate	Cover

Field Data Sheet for Unoccupied Locations, IFIM Transferability Studies—Continued

Observation Number	Date	Time	Mesohabitat Type	Depth (ft)	Rotations/ Seconds	Velocity (ft/sec.)	Temp. (°C)	Substrate	Cover

CODES FOR FILLING IN DATA SHEET

Mesohabitat Type (code & description to be filled in after preliminary field evaluation)

1 ____________________

2 ____________________

3 ____________________

4 ____________________

5 ____________________

6 ____________________

7 ____________________

8 ____________________

9 ____________________

10 ____________________

Substrate

1 = Diameter of < 3 mm (silt, sand)

2 = Diameter of 3 mm - 64 mm

3 = Diameter of > 64 mm

Cover

1 = No cover

2 = Object at least 6 inches high and with a cross section horizontal measurement of at least 1 ft

3 = Undercut object along bank

4 = Aquatic vegetation

5 = Terrestrial vegetation < 1 ft high

Appendix A5

Trip Notes for IFIM Transferability Studies

Trip Notes for IFIM Transferability Studies

Trip dates: ______________________

Areas of each mesohabitat type sampled

Mesohabitat type, with detailed description	Area sampled (sq. ft.)
1.	
2.	
3.	
4.	
5.	
6.	
7.	
8.	
9.	
10.	

Streamflow measurement on first day of sampling _____ cubic feet per second

Notes: (Describe stream and other field conditions, sampling and equipment problems, and other pertinent information.)

APPENDIX B

TRANSFERABILITY STUDY TEST RESULTS

Table B1. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Cherry Run, Brown Trout

Life Stage/Test Parameters	1st Data Set	2nd Data Set	1 & 2 Combined
Cherry Run, Adult Brown Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	0	0
b. occupied usable cells	5	20	25
c. unoccupied optimum cells	0	1	1
d. unoccupied usable cells	3	12	15
N. total number of cells	8	33	41
T. test statistic	Not applicable	-1.260	-1.266
Transferable? (T>1.6449)	Not applicable	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	5	20	25
b. occupied unsuitable cells	58	51	109
c. unoccupied suitable cells	3	13	16
d. unoccupied unsuitable cells	201	199	400
N. total number of cells	267	283	550
T. test statistic	2.631	5.007	5.678
Transferable? (T>1.6449)	Yes	Yes	Yes
Cherry Run, Juvenile Brown Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	1	1
b. occupied usable cells	50	60	110
c. unoccupied optimum cells	1	4	5
d. unoccupied usable cells	89	142	231
N. total number of cells	140	207	347
T. test statistic	-0.748	-0.470	-0.812
Transferable? (T>1.6449)	No	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	50	61	111
b. occupied unsuitable cells	11	5	16
c. unoccupied suitable cells	90	146	236
d. unoccupied unsuitable cells	114	66	180
N. total number of cells	265	278	543
T. test statistic	5.196	3.832	6.299
Transferable? (T>1.6449)	Yes	Yes	Yes

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B1. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Cherry Run, Brown Trout—Continued

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Cherry Run, Brown Trout Spawning			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	32		
b. occupied usable cells	13		
c. unoccupied optimum cells	22		
d. unoccupied usable cells	15		
N. total number of cells	82		
T. test statistic	1.107		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	45		
b. occupied unsuitable cells	12		
c. unoccupied suitable cells	37		
d. unoccupied unsuitable cells	173		
N. total number of cells	267		
T. test statistic	8.902		
Transferable? (T>1.6449)	Yes		
Cherry Run, Brown Trout Fry			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	6		
b. occupied usable cells	67		
c. unoccupied optimum cells	76		
d. unoccupied usable cells	124		
N. total number of cells	273		
T. test statistic	-4.751		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	73		
b. occupied unsuitable cells	2		
c. unoccupied suitable cells	200		
d. unoccupied unsuitable cells	12		
N. total number of cells	287		
T. test statistic	1.034		
Transferable? (T>1.6449)	No		

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B2. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Little Fishing Creek, Brook Trout

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Little Fishing Creek, Adult Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	0	0
b. occupied usable cells	17	20	37
c. unoccupied optimum cells	0	0	0
d. unoccupied usable cells	3	7	10
N. total number of cells	20	27	47
T. test statistic	Not applicable	Not applicable	Not applicable
Transferable? (T>1.6449)	Not applicable	Not applicable	Not applicable!
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	17	20	37
b. occupied unsuitable cells	44	56	100
c. unoccupied suitable cells	3	7	10
d. unoccupied unsuitable cells	205	205	410
N. total number of cells	269	288	557
T. test statistic	6.918	5.906	9.005
Transferable? (T>1.6449)	Yes	Yes	Yes
Little Fishing Creek, Juvenile Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	1	1
b. occupied usable cells	47	77	124
c. unoccupied optimum cells	0	0	0
d. unoccupied usable cells	95	102	197
N. total number of cells	142	180	322
T. test statistic	Not applicable	1.147	1.257
Transferable? (T>1.6449)	Not applicable	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	47	78	125
b. occupied unsuitable cells	17	16	33
c. unoccupied suitable cells	95	102	197
d. unoccupied unsuitable cells	113	110	223
N. total number of cells	272	306	578
T. test statistic	3.888	5.717	6.948
Transferable? (T>1.6449)	Yes	Yes	Yes

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B2. *One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Little Fishing Creek, Brook Trout—Continued*

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Little Fishing Creek, Brook Trout Spawning			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	26		
b. occupied usable cells	27		
c. unoccupied optimum cells	8		
d. unoccupied usable cells	2		
N. total number of cells	63		
T. test statistic	-1.801		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	53		
b. occupied unsuitable cells	8		
c. unoccupied suitable cells	10		
d. unoccupied unsuitable cells	198		
N. total number of cells	269		
T. test statistic	13.310		
Transferable? (T>1.6449)	Yes		
Little Fishing Creek, Brook Trout Fry			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	10		
b. occupied usable cells	58		
c. unoccupied optimum cells	91		
d. unoccupied usable cells	115		
N. total number of cells	274		
T. test statistic	-4.368		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	68		
b. occupied unsuitable cells	7		
c. unoccupied suitable cells	206		
d. unoccupied unsuitable cells	6		
N. total number of cells	287		
T. test statistic	-2.328		
Transferable? (T>1.6449)	No		

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B3. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Young Womans Creek, Brown Trout and Combined Brook/Brown Fry

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Young Womans Creek, Adult Brown Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	4	2	6
b. occupied usable cells	55	49	104
c. unoccupied optimum cells	0	0	0
d. unoccupied usable cells	86	82	168
N. total number of cells	145	133	278
T. test statistic	2.449	1.807	3.060
Transferable? (T>1.6449)	Yes	Yes	Yes
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	59	51	110
b. occupied unsuitable cells	22	5	27
c. unoccupied suitable cells	86	82	168
d. unoccupied unsuitable cells	121	128	249
N. total number of cells	288	266	554
T. test statistic	4.776	6.918	8.125
Transferable? (T>1.6449)	Yes	Yes	Yes
Young Womans Creek, Juvenile Brown Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	2	1	3
b. occupied usable cells	51	59	110
c. unoccupied optimum cells	16	12	28
d. unoccupied usable cells	187	161	348
N. total number of cells	256	233	489
T. test statistic	-1.042	-1.532	-1.833
Transferable? (T>1.6449)	No	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	53	60	113
b. occupied unsuitable cells	2	1	3
c. unoccupied suitable cells	203	173	376
d. unoccupied unsuitable cells	22	37	59
N. total number of cells	280	271	551
T. test statistic	1.458	3.164	3.324
Transferable? (T>1.6449)	No	Yes	Yes

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B3. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Young Womans Creek, Brown Trout and Combined Brook/Brown Fry —Continued

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Young Womans Creek, Brown Trout Spawning			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	34		
b. occupied usable cells	10		
c. unoccupied optimum cells	5		
d. unoccupied usable cells	3		
N. total number of cells	52		
T. test statistic	0.888		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	44		
b. occupied unsuitable cells	20		
c. unoccupied suitable cells	8		
d. unoccupied unsuitable cells	202		
N. total number of cells	274		
T. test statistic	11.599		
Transferable? (T>1.6449)	Yes		
Young Womans Creek, Brook/Brown Trout Fry			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	19		
b. occupied usable cells	59		
c. unoccupied optimum cells	75		
d. unoccupied usable cells	122		
N. total number of cells	275		
T. test statistic	-2.161		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	78		
b. occupied unsuitable cells	11		
c. unoccupied suitable cells	197		
d. unoccupied unsuitable cells	22		
N. total number of cells	308		
T. test statistic	-0.595		
Transferable? (T>1.6449)	No		

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B4. One-Sided Chi Square Tests for Habitat Suitability Criteria Transferability, Young Womans Creek, Brook Trout

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Young Womans Creek, Adult Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells		3	
b. occupied usable cells		51	
c. unoccupied optimum cells		0	
d. unoccupied usable cells		82	
N. total number of cells		136	
T. test statistic		2.158	
Transferable? (T>1.6449)		Yes	
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells		54	
b. occupied unsuitable cells		5	
c. unoccupied suitable cells		82	
d. unoccupied unsuitable cells		128	
N. total number of cells		269	
T. test statistic		7.123	
Transferable? (T>1.6449)		Yes	
Young Womans Creek, Juvenile Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells		3	
b. occupied usable cells		54	
c. unoccupied optimum cells		14	
d. unoccupied usable cells		200	
N. total number of cells		271	
T. test statistic		-0.354	
Transferable? (T>1.6449)		No	
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells		57	
b. occupied unsuitable cells		1	
c. unoccupied suitable cells		214	
d. unoccupied unsuitable cells		53	
N. total number of cells		325	
T. test statistic		3.361	
Transferable? (T>1.6449)		Yes	

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B5. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Whitehead Run, Brook Trout

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Whitehead Run, Adult Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	2	2
b. occupied usable cells	11	22	33
c. unoccupied optimum cells	0	0	0
d. unoccupied usable cells	13	24	37
N. total number of cells	24	48	72
T. test statistic	Not applicable	1.445	1.475
Transferable? (T>1.6449)	Not applicable	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	11	24	35
b. occupied unsuitable cells	48	36	84
c. unoccupied suitable cells	13	24	37
d. unoccupied unsuitable cells	197	184	381
N. total number of cells	269	268	537
T. test statistic	2.965	5.065	5.807
Transferable? (T>1.6449)	Yes	Yes	Yes
Whitehead Run, Juvenile Brook Trout			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	0	1	1
b. occupied usable cells	58	90	148
c. unoccupied optimum cells	0	1	1
d. unoccupied usable cells	129	155	284
N. total number of cells	187	247	434
T. test statistic	Not applicable	0.387	0.468
Transferable? (T>1.6449)	Not applicable	No	No
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	58	91	149
b. occupied unsuitable cells	3	7	10
c. unoccupied suitable cells	129	156	285
d. unoccupied unsuitable cells	81	52	133
N. total number of cells	271	306	577
T. test statistic	5.003	3.694	6.346
Transferable? (T>1.6449)	Yes	Yes	Yes

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Table B5. One-Sided Chi-Square Tests for Habitat Suitability Criteria Transferability, Whitehead Run, Brook Trout—Continued

Life Stage/Test Parameter	1st Data Set	2nd Data Set	1 & 2 Combined
Whitehead Run, Brook Trout Spawning			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	22		
b. occupied usable cells	40		
c. unoccupied optimum cells	13		
d. unoccupied usable cells	40		
N. total number of cells	115		
T. test statistic	1.273		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	62		
b. occupied unsuitable cells	3		
c. unoccupied suitable cells	53		
d. unoccupied unsuitable cells	157		
N. total number of cells	275		
T. test statistic	10.019		
Transferable? (T>1.6449)	Yes		
Whitehead Run, Brook Trout Fry			
Optimum Versus Usable Test Parameter			
a. occupied optimum cells	6		
b. occupied usable cells	45		
c. unoccupied optimum cells	15		
d. unoccupied usable cells	153		
N. total number of cells	219		
T. test statistic	0.603		
Transferable? (T>1.6449)	No		
Suitable Versus Unsuitable Test Parameter			
a. occupied suitable cells	51		
b. occupied unsuitable cells	6		
c. unoccupied suitable cells	168		
d. unoccupied unsuitable cells	44		
N. total number of cells	269		
T. test statistic	1.762		
Transferable? (T>1.6449)	Yes		

NOTE: For the above, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more.

Appendix C

Field Data Collection Problems

C1.0 GENERAL DISCUSSION OF FIELD DATA COLLECTION PROBLEMS

1. In some cases, study sites were selected without considering influences of aquatic vegetation, or effects of human activities. Sites should be free of human activities to the extent possible.

2. At some sites, benchmarks were not established on a permanent structure when the CDS was collected.

3. In some cases, end pin reference points and benchmark points were not clearly differentiated.

4. Field data sheets for some sites showed inadequate description of benchmarks and reference marks. The description should include the type of marking (PK nail, paint spot, etc.), type and size of object benchmark is located on (12" birch, large rock), and a general location (left bank 10 ft from edge of water, between run and riffle).

5. Partial data set

   a. In some cases, data sheets did not describe the benchmark used for the survey.

   b. In some cases, end pin elevations were not surveyed. These elevations are necessary to resolve elevation inconsistencies among data sets.

   c. Elevations of end pins and water surfaces were not computed in the field to check for errors.

   d. In some instances, transect location appears to be based on proximity to the other transects, rather than representativeness. The importance of transect selection can not be over stressed, considering a single transect represents a mesohabitat for an entire stream segment.

6. Four streams in the Maryland Piedmont appear not to be in dynamic equilibrium, and actively adjusting stream bed or banks. The channel changes are more apparent and extreme than observed elsewhere. Changes in flows, resulting from withdrawals from these streams, may alter substrate, and affect fishery habitat. Effects of changing substrate were not considered in this study (C. Spaur, U.S. Army Corps of Engineers, written communication 9/20/95, and oral communication 10/27/97). The data for the Maryland Piedmont streams should be used cautiously pending further evaluation of these effects.

C2.0 SPECIFIC STREAM DATA COLLECTION PROBLEMS

Stream Name	Segment	Problems
Black Ash Run (Luzerne County)	1	Eliminated, no trout observed. Owner said stream becomes dry in summer.
Broad Run (Franklin County)	1	Eliminated from study because site was located too close to segment 2 site.
Broad Run (Franklin County)	2	Changed to segment 1 when original segment 1 was eliminated. A permanent benchmark was not established at the site when the CDS was collected. The original run transect was not satisfactory for low flow work, so it was relocated upstream. The original riffle transect was skewed across the stream, resulting in a sloping stream bottom. Returning crews had difficulty locating the tail pin at the skewed riffle transect.
Cedar Run (Centre County)	1	Aquatic vegetation may have affected velocity measurements.
Dunlap Run (Clearfield County)	1	Leaf accumulation affected water surface elevation, possibly due to very narrow stream.
First Mine Branch (Baltimore County)	1	Possible influence of old mill works on site.
Fowler Hollow Run (Perry County)	1	Original site was located within segment 2 because of inaccurate existing mapping. Site was relocated upstream to the midpoint of segment 1. The use of a hand-held Global Positioning System (GPS) receiver would have eliminated this problem.
Georgetown Branch (Bedford County)	1	Stream eliminated because of no trout reproduction.
Gillis Falls (Carroll County)	1	Forested wetlands above bankfull elevation may influence hydraulics at high flow. Small mill dams may have been present in the past. Stream is presently cutting through mill pond deposits, resulting in potential channel instability.
Gillis Falls (Carroll County)	2	Possible anomalous quantity of gravel for this stream.
Greene Branch (Baltimore County)		Large volume of fine grained micaceous sediment, may be result of accelerated erosion of uplands due to human activities.
Kase Run (Montour County)	1	Stream eliminated because of no trout reproduction.

Stream Name	Segment	Problems
Lanigan Branch (Elk County)	1	Gated access road, unable to gain access.
Laurel Run (Juniata County)	2	Eliminated from study due to poor access.
Letort Spring Run (Cumberland County)	1	Vegetation upstream of the run transect caused unusual column velocities at some verticals, necessitating measuring column velocities at 0.2, 0.6 and 0.8 times the depth. Original transect relocated a short distance because of vegetation affecting velocity measurements.
Letort Spring Run (Cumberland County)	2	Original transect located in reach with split channel. Transect re-located downstream. Seasonal variations in vegetation downstream from transect may have caused seasonal variations in depth/velocity/discharge relationships.
Little Fishing Creek (Clinton County)	1	Skewed riffle transect resulted in sloping stream bottom and water surface.
Meyers Run (Centre County)	1	Leaf accumulation affected water surface elevation, possibly due to very narrow stream.
Piney Run (Carroll County)		Stream appears to be cutting through mill pond deposits, and streambank is unstable. Forested wetlands in vicinity of site at and above top of bank may influence hydraulics at high flows.
Sicily Run (McKean County)	1	Gated access road, unable to gain access.
Sugar Camp Run (Jefferson County)	1	Eliminated, water quality could not support a natural trout population.
Third Mine Branch (Baltimore County)		Water depths seem to have changed substantially at run site on different visits, probably due to erosion and deposition of bed materials. Stream appears to be cutting through mill pond deposits, and streambank is unstable. Forested wetlands in vicinity of site at and above bankfull may influence hydraulics at high flows.
Three Square Hollow (Cumberland County)	1	Stream eliminated because of no trout reproduction.
Upper Stimpson Run (Clinton County)	1	Eliminated, no trout or other fish observed.
Wapwallopen Creek (Luzerne County)	5	Eliminated from study due to poor access.

Appendix D

Hydrologic Computations for Selected Watersheds

D1.0 INTRODUCTION

General aspects of the hydrologic computations are described in section 5.5. The hydrologic computations for certain streams, where complex geology, withdrawals, or WWTP flows complicated the hydrology, are described in this appendix.

D2.0 STUDY SITES ON MONOCACY CREEK, NORTHAMPTON COUNTY

The hydrology for the study sites on Monocacy Creek is complicated by the fact that part of the watershed is underlain by shale rock, and part is underlain by limestone rock. These different rock types have different hydrologic characteristics. The study sites on Monocacy Creek are located in limestone areas.

U.S. Geological Survey (USGS) has operated a stream gage on Monocacy Creek at Bethlehem since 1949. Wood and others (1972) estimate there is an unmeasured underflow at the Monocacy Creek gage of 12 cfs on an average annual basis.

The hydrology for the three study sites was estimated by using the flow data collected at the study sites and the daily flow at the gage on the same date to solve water balance equations. Water balance equations basically show that the amount of water coming into the study site equals the amount of water leaving the study site. The water balance equations were used to estimate the flows from each type of geology for the date on which the complete data set (CDS) was collected. The observed daily flow at the gage was adjusted by adding the average underflow at the gage, and then water balance equations were written for each study site to account for streamflows contributed by each type of geology, and the underflow bypassing that site. Then flows for each type of geology were converted to unit flow (cubic feet per second per square mile, csm) rates, and used to estimate hydrology for the study sites. For the purpose of writing the water balance equations, the gage was considered as a fourth study site.

The water balance equations used in this study had the general form that the water coming into the study site was equal to the streamflow leaving the upstream segment, plus the runoff and spring flow generated in the study segment, minus any underflow bypassing the study site. These equations can be represented mathematically as:

$$\Sigma\, rL_i * AL_i + \Sigma\, rS_i * AS_i + \Sigma S_i - \Sigma\, U_i = Q_n \quad \text{(D1)}$$

where:

Σ = the summation operator;
$*$ = the multiplication operator;
rL_i = the runoff rate from the limestone part of the i^{th} segment;
rS_i = the runoff rate from the shale part of the i^{th} segment;
AL_i = the area of the i^{th} segment underlain by limestone;
AS_i = the area of the i^{th} segment underlain by shale;
U_i = the incremental underflow bypassing the i^{th} study site;
S_i = the spring flow in the i^{th} study segment;
Q_n = the streamflow measured at the n^{th} study site for a specific measurement.

In these equations, the summations are for all the study sites contributing flow to the n^{th} study site.

The underflow at the gage probably varies with flow rate, but the only data available regarding that underflow is the average daily flow of 12 cfs (Wood and others, 1972). Because of the lack of data, the underflow was assumed to be constant at 12 cfs. The sum of the underflows passing the respective study sites should equal 12 cfs, resulting in the following water balance equation:

$$\sum U_i = 12 \text{ cfs} \quad \text{(D2)}$$

For Monocacy Creek, the spring flow terms were assumed to be zero, since there are no significant springs in this watershed (Flippo, 1974). Therefore, these equations need to be solved for the runoff rates from the different rock types, and the amount of underflow bypassing the respective study site. However, there are four segments, each with two values of runoff and an underflow, resulting in five equations and 12 unknown variables. To reduce the number of unknowns, the runoff rates for each rock type were assumed equal for each segment, and the shale runoff rates were set to zero for segments where shale is not present. This results in five equations and six unknown variables. To solve the equations, another unknown variable had to be assumed. Most of the watershed above study site 1 is underlain by shale, and only a small part is underlain by limestone. Therefore, it was assumed that negligible underflow would bypass this study site. Because of this assumption, and because the variables of greatest interest are the runoff rates for the different rock types, the underflow from segment 1 was assumed to be zero.

These equations were written in matrix form in the Excel spreadsheet program, and solved using the matrix functions in Excel.

The solution is summarized in Table D1. In this table, the unit runoff rates (csm) for each rock type are shown in the first two rows of the second column. The flow rates for each rock type (column 1 multiplied by drainage area in that rock type), the underflow, and the total flow for each study site are shown in the remaining columns. The underflow is the total amount of underflow bypassing the respective study site. For example, at the time the CDS was collected, the underflow at study site 2 is estimated to be 22.83 cfs, while the underflow at sites 3 and 4 are estimated as 17.06 and 11.99 cfs, respectively, based on the assumptions used to solve the water balance equations. The estimated streamflow in row 4 is the sum of the runoff and underflow.

Table D1. Summary of Monocacy Creek Flows for Complete Data Set

Water Balance Component	Unit Flow Rate (csm)	Flow Rate Site 1 (cfs)	Flow Rate Site 2 (cfs)	Flow Rate Site 3 (cfs)	Flow Rate Site 4 (cfs)
Runoff from shale	0.75	5.63	10.99	10.99	10.99
Runoff from limestone	1.84	1.79	36.03	49.28	54.98
Accumulated underflow	—	0	-22.83	-17.06	-11.99
Estimated total streamflow	—	7.42	24.19	43.21	53.98
Measured streamflow	—	7.41	24.20	43.20	54.00

Conceptually, the estimated underflow could be assumed constant for all flow conditions, but that assumption is probably unrealistic, considering the underflow has been estimated using only one field

data set. The variation of underflow rates with streamflow was estimated by assuming that the underflow is a constant percentage (or ratio) of the streamflow. The ratio of underflow bypassing each study site for the CDS was estimated by dividing the amount of underflow by the measured flow at each study site Then the measured flow at the site was adjusted to estimate the amount of flow that would have occurred in the absence of the underflow. To make the adjustment, the underflow was computed by multiplying the measured flow by the underflow ratio and adding the underflow to the measured flow. The computations and the resulting flow at the study site(s) are shown in Table D2.

Table D2. Summary of Monocacy Creek Underflow Estimates

Study Site	Measured Flow (cfs)	Accumulated Underflow * (cfs)	Accumulated Underflow Ratio *	Adjusted Flow (cfs)
1	7.41	0	0	7.41
2	24.20	-22.80	-0.942	47.00
3	43.20	-17.06	-0.394	60.25
4	54.00	-11.99	-0.221	65.96

* Minus sign indicates underflow bypassing study site.

The procedure used to compute the necessary hydrology for the Monocacy Creek study sites included the following steps:

- Jordan Creek at Schnecksville (L. Taylor, SRBC, oral communication; C. Wood, USGS, oral communication) was used to represent the runoff from the part of the Monocacy Creek watershed underlain by shale;
- Flow rates for Jordan Creek at selected probabilities of exceedance were tabulated and converted to unit flow rates (csm), and then multiplied by the drainage area at the Monocacy Creek gage underlain by shale;
- Flow rates at the Monocacy Creek gage were tabulated at the same selected probabilities of exceedance, and adjusted by adding the underflow, estimated by multiplying the actual flow by the underflow ratio (0.221) at the gage;
- The flow rates for areas underlain by shale were subtracted from the adjusted Monocacy Creek gage flow rates to obtain the flow rates for areas underlain by limestone;
- The flow rates at the gage for the areas underlain by limestone were converted to unit flow rates (csm), and then multiplied by the drainage area of each study site underlain by limestone to obtain the corresponding flow for that rock type and study site;
- For each study site, the Jordan Creek unit flow rates (csm) were multiplied by the area underlain by shale, and added to the corresponding flow rates for the areas underlain by limestone, to estimate the total flow rate for that study site, neglecting the underflow;
- For each study site, the unadjusted total flow rates were adjusted using the accumulated underflow ratio shown in Table D2.

D3.0 STUDY SITES ON BUSHKILL CREEK, NORTHAMPTON COUNTY

Bushkill Creek is adjacent to Monocacy Creek, and has similarly mixed shale and limestone geology. The study sites on Bushkill Creek also are located in limestone.

The flows for the Bushkill Creek study sites were computed by multiplying the unit flow rates (csm) for each rock type, determined as described for Monocacy Creek, by the drainage area of Bushkill Creek underlain by the respective rock type, and summing the products. Flow values for study site 2 were adjusted by adding 3.57 cfs to represent the average daily net import to the segment discharged by the Nazareth WWTP (S. Runkle, Pa. Dept. of Environmental Protection, oral communication).

D4.0 STUDY SITES ON CEDAR CREEK, LEHIGH COUNTY

The hydrology of the Cedar Creek Basin is complicated by varying rock types, the discharge of Schantz Spring to the watershed, and the fact that the City of Allentown withdraws most of the flow of Schantz Spring for water supply (Wood and others, 1972).

Because only about 20 percent of the Cedar Creek Watershed is underlain by freestone (Wood and others, 1972), the watershed was assumed to be entirely underlain by limestone. Schantz Spring is located within the Cedar Creek Watershed, but most of the drainage area contributing to Schantz Spring is in adjacent surface water basins (Wood and others, 1972).

The adjusted drainage area for Cedar Run was determined by subtracting the portion of the drainage area of Schantz Spring within the Cedar Creek drainage area (2.15 square miles) (Wood and others 1972) from the drainage area at the study site (11.58 square miles).

Although the amount of spring flow reaching Cedar Creek probably varies with the total spring flow, the only data readily available is the average daily flow estimated as 1.6 mgd (2.48 cfs) (Wood and others, 1972).

The unadjusted flow for Cedar Creek was computed by multiplying the unit flow rates (csm) for the limestone area, as determined for Monocacy Creek, by the adjusted drainage area for Cedar Run at the study site. Then these flows were adjusted by adding the part of the Schantz Spring flow that reaches Cedar Run.

D5.0 STUDY SITE ON NANCY RUN, BERKS COUNTY

Nancy Run is entirely underlain by limestone rock. The necessary hydrology was determined by multiplying the adjusted unit flow rates (csm) for areas underlain by limestone, determined for the Monocacy Creek gage (section D2.0), by the drainage area at the Nancy Run study site.

D6.0 STUDY SITE ON TROUT CREEK, LEHIGH COUNTY

About 55 percent of the Trout Creek Watershed is within the Reading Prong physiographic subprovince. The Reading Prong is underlain by metamorphic rocks, which have very different hydrology compared to the limestone or shale areas.

Furnace Creek near Robesonia is the only gage available to represent flows from the metamorphic rocks. This gage has short records (1983-93), and is affected by water supply withdrawal from a small reservoir. Based on withdrawal data for 5 years during the period 1983 to 1990 (T. Denslinger, Pa. DEP, oral communication), the average daily withdrawal was estimated as 0.66 cfs, with a standard deviation of 0.11 cfs.

To obtain the hydrology for Trout Creek, the flow rates for Furnace Creek were tabulated, adjusted for the estimated average daily withdrawal, and multiplied by the appropriate ratio of drainage areas to obtain the flows from the metamorphic rocks on Trout Creek. The adjusted unit flow rates for areas underlain by limestone determined for Monocacy Creek (section D2.0) were multiplied by the drainage area of Trout Creek underlain by limestone rocks, and added to the flow rates from the metamorphic rocks to obtain flow rates at the study site.

D7.0 STUDY SITE ON SPRING CREEK, BERKS COUNTY

The geology of the Spring Creek Watershed is very complex, because part of the watershed is underlain by metamorphic rocks, part is underlain by limestone, and part is underlain by shale.

The flow rates for the limestone rock were estimated from the flow rates for areas underlain by limestone determined for Monocacy Creek, (section D2.0). The flow rates for areas underlain by metamorphic rocks were estimated using the flow rates at the Furnace Creek gage, adjusted for the effect of the water supply withdrawal (section D6.0). The flow rates for the area underlain by shale rocks were estimated using the unit flow rates for Jordan Creek at Schnecksville. The flow rates for each type of geology were determined using a ratio of drainage areas, and then summed to obtain total flow rates.

D8.0 STUDY SITES ON LETORT SPRING RUN, CUMBERLAND COUNTY

The hydrology of Letort Spring Run is complicated by at least 16 springs in the limestone strata on the watershed (Barrick, 1977). While there are no specific flow data to estimate the drainage area for these springs, it is likely the ground-water divide does not coincide with the surface water divide (L. Taylor, SRBC, oral communication).

USGS has operated a stream gage near the mouth of the watershed since 1976. Several flow measurements were made at other locations in the watershed by USGS in calendar years 1990 (Loper and others, 1991) and 1991 (Durlin and Schaffstall, 1992). Since these measurements were made at locations other than the sites measured for this study, the USGS data were used only to check the procedures developed.

The first study site is located a short distance upstream from the watercress beds at Bonny Brook. The second study site is located downstream from the Harmony Hall Road bridge, east of the Army War College. For the purpose of estimating the hydrology, an additional study site was assumed at the USGS gage. Based on a map prepared by Barrick (1977), the springs appear to occur only in the first two segments.

After several trials at estimating the annual flow duration at the study sites, the five sets of flow measurements available for the study sites were used to solve the water balance equations (equation D1), similar to the solution for Monocacy Creek. However, this watershed is entirely underlain by limestone, and therefore, the first two terms in equation D1 become one term. Also, the springs are assumed to be important factors in the hydrology, although Flippo (1974) does not show any significant springs in this watershed. Therefore, the unknown variables in the equations are the runoff rates for each segment and the spring flow rates for segments 1 and 2. In effect, the flow data at the study sites and the equations are used to partition the observed flow rates at the gage into flow components at the study sites.

The measured flow at the gage was assumed to be represented by the daily flow on the same day the measurements were made.

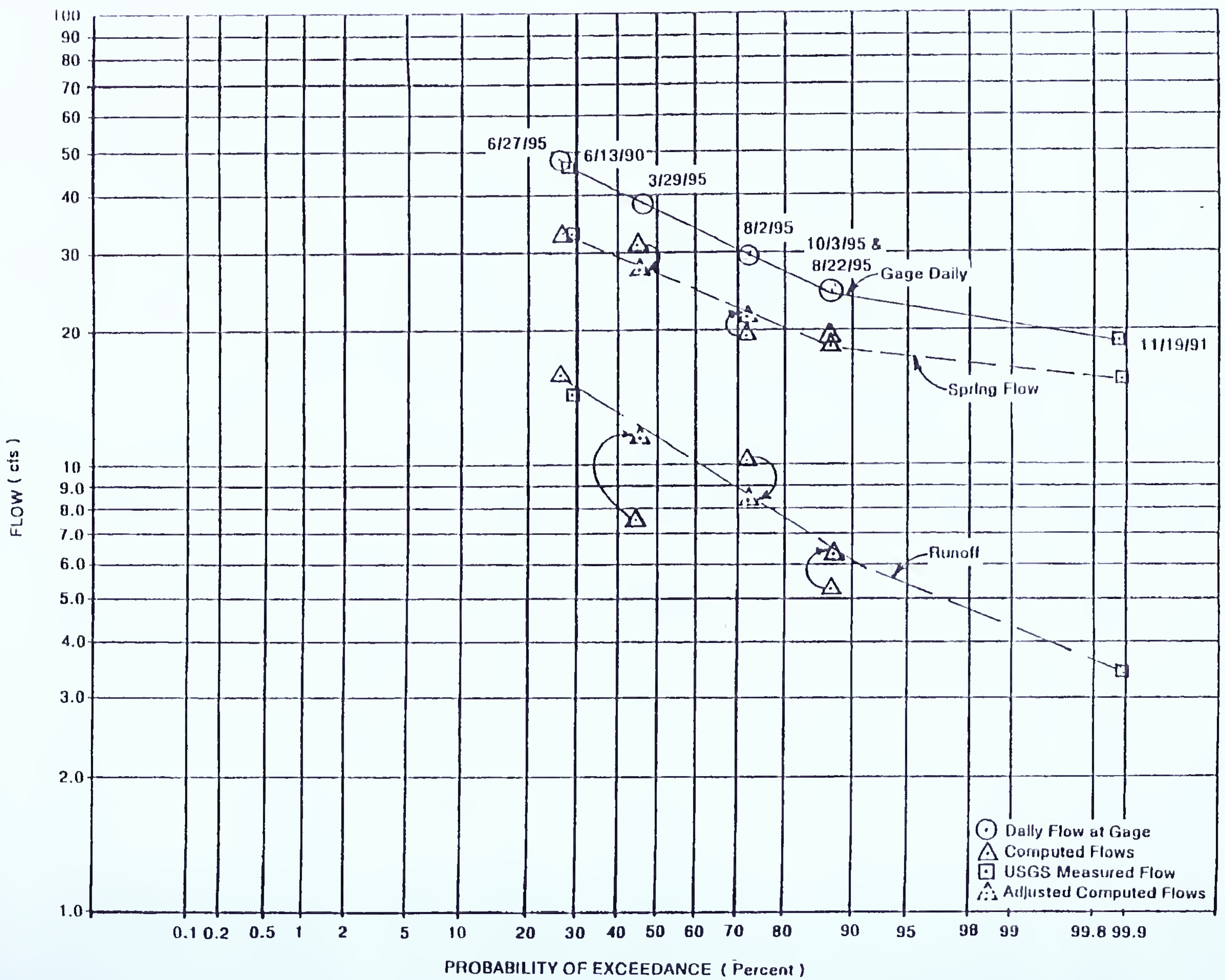


Figure D1. Letort Spring Run Flow Duration at Stream Gage

These equations were solved for each of the five flow measurements. For each measurement. there are three equations and five unknown variables. The number of unknown variables was reduced by assuming the runoff rates (csm) were the same for each segment.

The solutions for each event were tabulated along with the probability of exceedance of the daily flow rate at the gage. This tabulation showed inconsistencies among events, probably due to the assumptions involved.

For each event, the estimated runoff and spring flows, and observed flows at the gage were plotted on log-normal probability paper, and then fitted by eye, as shown in Figure D1. For the measurement taken on March 29, 1995, the water balance calculation apparently overestimates the spring flow and underestimates the runoff, compared to the trend of the other measurements, so the computed values were adjusted to obtain the best fit and maintain the total flow, as shown by arrows and dashed symbols in the figure. For the measurement taken on August 2, 1995, the water balance calculation appears to underestimate the spring flow and overestimate the runoff, so similar adjustments were made, as shown in the figure. Note the adjusted values plot very close to the eye-fit line. Also, note that measurements made on August 22, 1995, and October 3, 1995, were identical at the gage, but the computed spring flow and runoff values were slightly different. Minor adjustments were made to these flows so that they coincide.

The flow duration for the gage and the measured flows at each site were plotted on log-normal probability paper, as shown in Figure D2. Note the measurements made at both study sites on June 27, 1995, are anomalous, compared to the other measurements. This is probably due to significant rainfall at the time of this measurement, which violates the steady-state assumption implicit in the water balance calculations. For that reason, the measurement was ignored. The remaining measurements were again fitted by eye.

These curves were extrapolated to higher and lower flows as follows. The flow duration curve for study site 2 parallels the gage curve within the range of the measured flows (probabilities of exceedance between 45 percent and 87 percent). The curve was extrapolated to lower flows by assuming the two lines remain parallel, which implies a constant percentage difference between the gage flow and the study site 2 flow. To allow for increased runoff between study site 2 and the gage at higher flows, a straight line extrapolation was assumed for flows greater than the measured flows (probabilities less than 45 percent).

For study site 1, the measurements do not follow the expected pattern, especially if the June 27, 1995, measurement is included, but the eye-fit line through those points between 45 percent and 87 percent probability seems reasonable. A straight line extrapolation to probabilities less than 45 percent was assumed. The curve was extrapolated to probabilities greater than 87 percent by assuming a constant difference between the gage flows and the site 1 flows.

The necessary hydrology at the Letort Spring Run study sites was determined using the flow duration curves, shown in Figure D2, as follows:

- The flows at the gage were determined from the gage record;
- The probability of those flows at the gage was determined from the gage flow duration curve; and
- The flows at the study sites were computed by summing the runoff and spring flows for the respective segment.

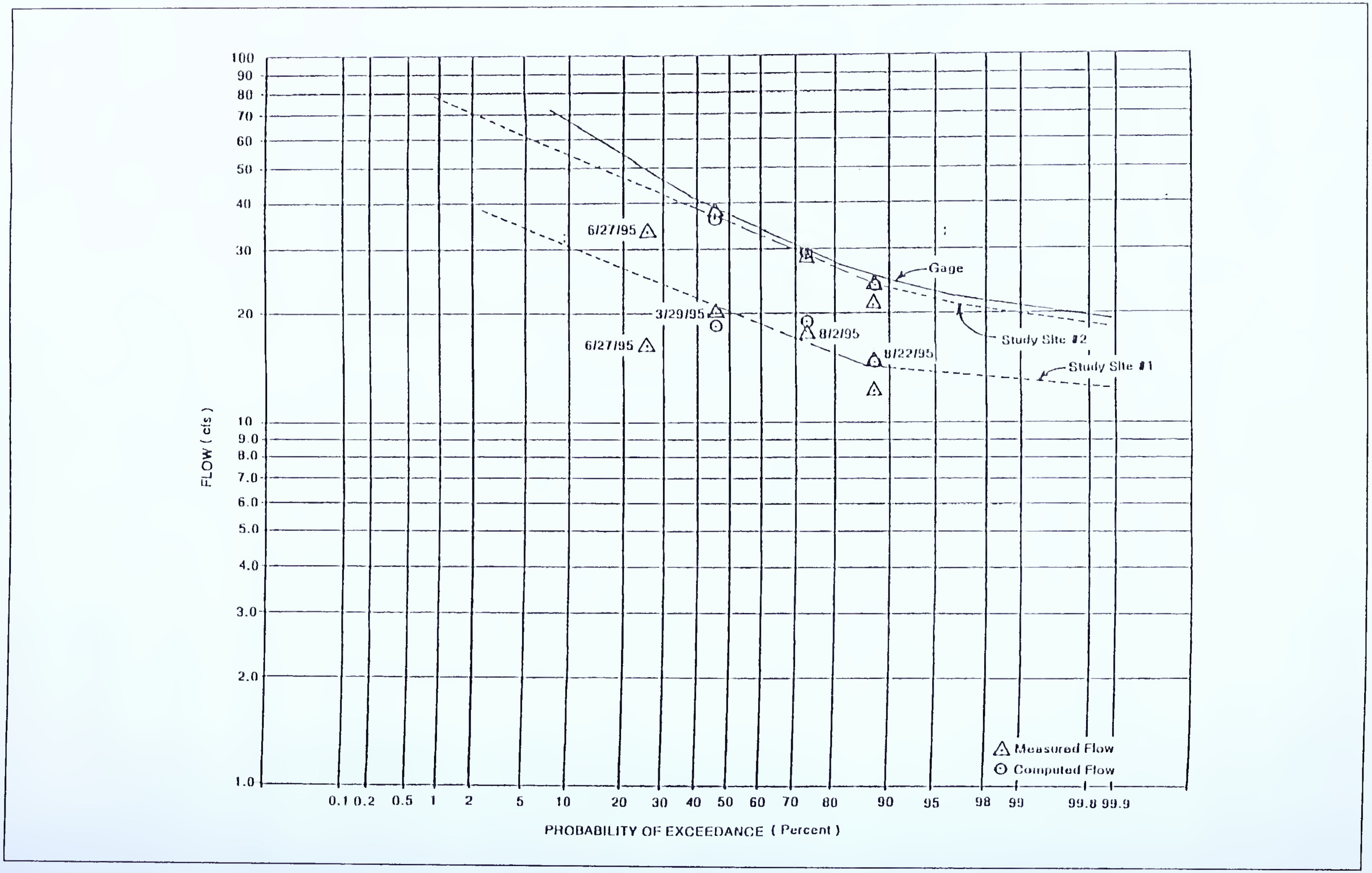


Figure D2. Letort Spring Run Flow Duration for Study Sites and Stream Gage

The runoff rates were obtained from Figure D1, converted to unit flow rates (csm), and plotted on log-normal probability paper, as shown in Figure D3. These runoff rates were used to determine runoff rates for Trindle Spring Run, Big Spring Creek, and Falling Spring Run, which were believed to have similar runoff characteristics.

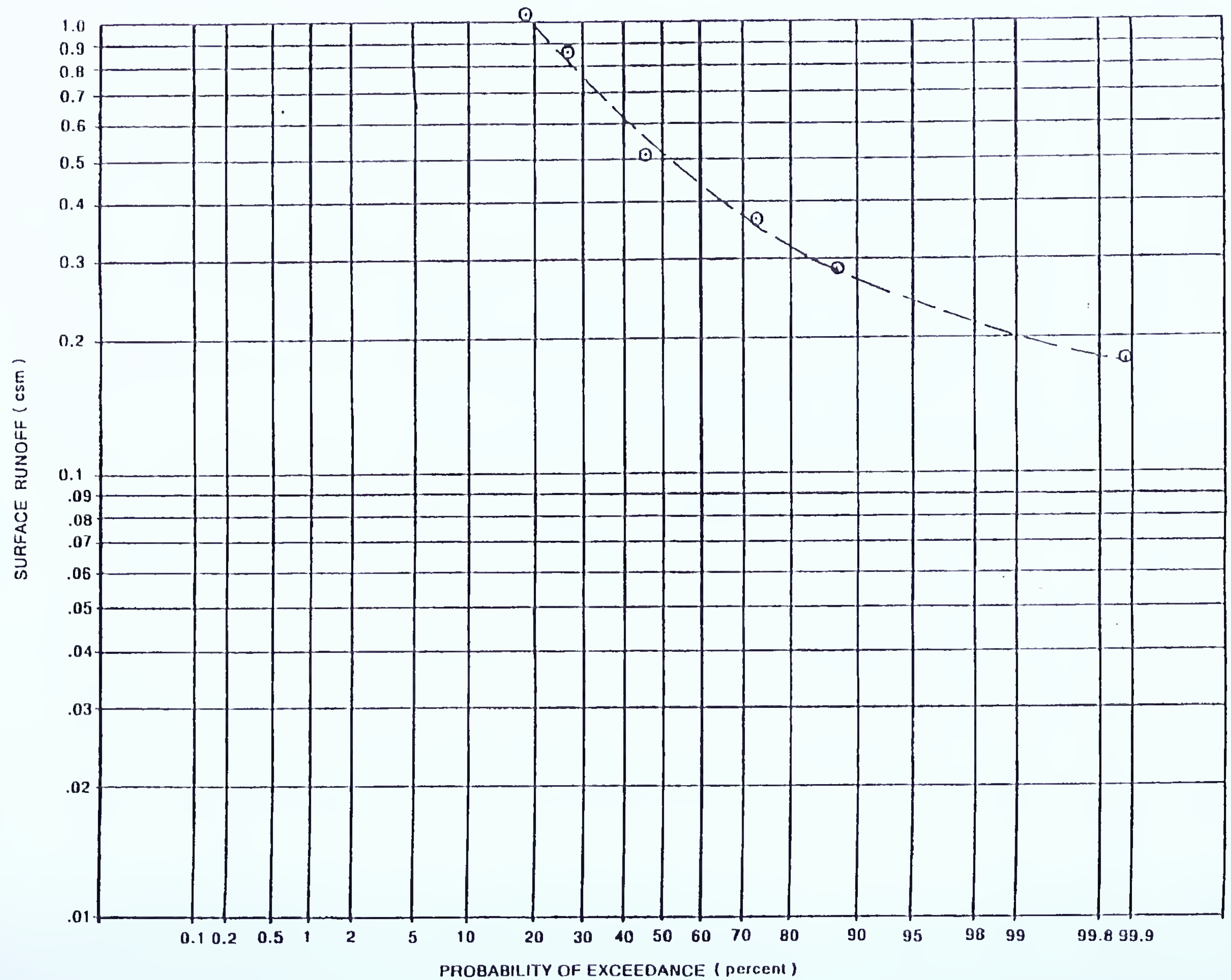


Figure D3. Letort Spring Run Flow Duration for Runoff Only

D9.0 STUDY SITE ON TRINDLE SPRING RUN, CUMBERLAND COUNTY

USGS measured Trindle Spring Run flows on June 13, 1990 (Loper and others, 1991), and November 18, 1991 (Durlin and Schaffstall, 1992), at a location close to the study site. These flow measurements range from 12 to 21 cfs, and did not appear to have any relationship to flows at nearby gages. For that reason, and the fact that the drainage area at the USGS site is about 8 percent less than the drainage area at the site used in this study, the USGS measurements were not used to develop hydrology.

Flippo (1974) shows two springs on the Trindle Spring Run Watershed, Trindle Spring and Silver Spring, and shows two sets of flow measurements for each spring. For Trindle Spring, the measured flow on November 6, 1970, was 960 gpm (2.14 cfs); the measured flow on November 11, 1971, was 730 gpm (1.63 cfs). For Silver Spring, the flows measured on the same dates were 1,690 gpm (3.77 cfs) and 1,890 gpm (4.21 cfs), respectively. Flippo (1974) estimates the median flow rates for Trindle Spring and Silver Spring as 850 gpm (1.89 cfs) and 1,900 gpm (4.23 cfs), respectively. Because the absolute variation in the measured flow rates is small, and no additional data are available, the spring flow rate was assumed constant at the sum of the median values.

The annual flow duration curve was estimated by multiplying the unit runoff rates (csm) for Letort Spring Run, as shown in Figure D3, by the drainage area at the site, and adding the spring flow.

Annual mean and median flows, seasonal flow duration, and median monthly time series were estimated as follows:

- The appropriate flow values were determined from the Letort Spring Run gage data;
- The probability of those flows was determined from the Letort Spring Run gage flow duration curve;
- The runoff rates for Letort Spring Run were determined from Figure D3 at the same probability; and
- The runoff rates were multiplied by the site drainage area and the median spring flows were added to obtain Trindle Spring Run flows.

D10.0 STUDY SITE ON BIG SPRING CREEK, CUMBERLAND COUNTY

The hydrology of Big Spring Creek is complicated by a large spring (Big Spring) near the headwaters, and upstream of the study site. Becher and Root (1981) estimate Big Spring diverts between 5 and 10 percent of the flow of the adjacent Yellow Breeches Creek. Flippo (1974) shows nine measurements of Big Spring flows that range from 7,500 gpm (16.7 cfs) to 13,900 gpm (31.0 cfs). He estimates the maximum spring flow as 15,000 gpm (33.5 cfs), and the minimum spring flow as 6,000 gpm (13.4 cfs). The USGS measured the spring flow on June 14, 1990 (Loper and others, 1991), and November 20, 1991 (Durlin and Schaffstall, 1992). The flow rate was 24 cfs on both dates. An additional measurement was made for this study on January 27, 1995. Because the spring flow data shows wide variation, the spring flow could not be assumed constant, as for Trindle Spring Run.

Gage flow data are the only information available to estimate the probability of the measured spring flows. The probability of exceedance of the spring flow was assumed to be equal to the probability of the streamflow on the same date at one or more nearby gages, Conodoguinet Creek near Hogestown, Yellow Breeches Creek near Camp Hill, or Letort Spring Run near Carlisle.

Initial attempts to estimate the probability of the spring flows by using probabilities of the flows for these gages, produced uncertain results. Further comparisons of flows based on these three gages showed flows based on Letort Spring Run gage data were closest to the observed flows at the study site.

The nine spring flows shown by Flippo (1974), the spring flow value collected for this study, and the probability of exceedance are summarized in Table D3. These data were plotted on log-normal probability paper, as shown in Figure D4.

The six spring flow values for the months of June through October plot around a straight line (Figure D4), which increases with decreasing probability. The four spring flow values for the months of November and January also plot around a straight line, but flows decrease with decreasing probability, and are significantly less than the summer and early fall data. This suggests that season affects the spring flows, but the data are insufficient to confirm that conclusion. Since the behavior of the late fall and winter data is anomalous and unexplainable, it was ignored in subsequent analyses. The summer and early fall curve was used in estimating the probability of the spring flows to synthesize a flow duration curve for the study site.

After several unsuccessful attempts, the following procedure was developed to estimate the flow duration curve for Big Spring Creek:

- Multiply the Letort Spring Run runoff rates (csm) (Figure D3) by the drainage area at the Big Spring Creek study site;
- Add assumed spring flow rates that ranged from 23 cfs at 98 percent probability of exceedance to 32.8 cfs at 20 percent probability of exceedance, as shown in Figure D4; and
- Plot the resulting flow duration curve and the measured flows at the study site, assuming the probabilities of the measured flows are the same as the probabilities of the flows at the Letort Spring Run gage on the same date.

Comparison of the measured flows at the Big Spring Creek study site with the flow duration curve showed reasonable agreement and better fit than other approaches, so this flow duration curve was adopted.

The necessary hydrology at the study site was determined from this flow duration by using flows and probabilities for the Letort Spring Run gage.

Table D3. Big Spring Creek, Cumberland County, Spring Flow Data and Concurrent Flows at Nearby Gages

Spring Flow Data		Conodoguinet		Yellow Breeches		Letort Spring Run	
Date	Spring cfs	Flow cfs	Exceedance Probability percent	Flow cfs	Exceedance Probability percent	Flow cfs	Exceedance Probability percent
06/09/44	31.00	313	51				
07/07/44	28.77	360	45				
08/17/49	26.76	113	90				
08/20/65	24.08			92	99.3		
01/13/67	16.73			139	78		
01/17/67	18.29			148	74		
10/16/67	22.97	102	93	120	88.4		
10/05/71	26.76	152	78.8	145	75.3		
11/11/71	25.42	290	54.4	202	53.2		
01/27/95	16.49	894	16	493	11.7	66	10.75

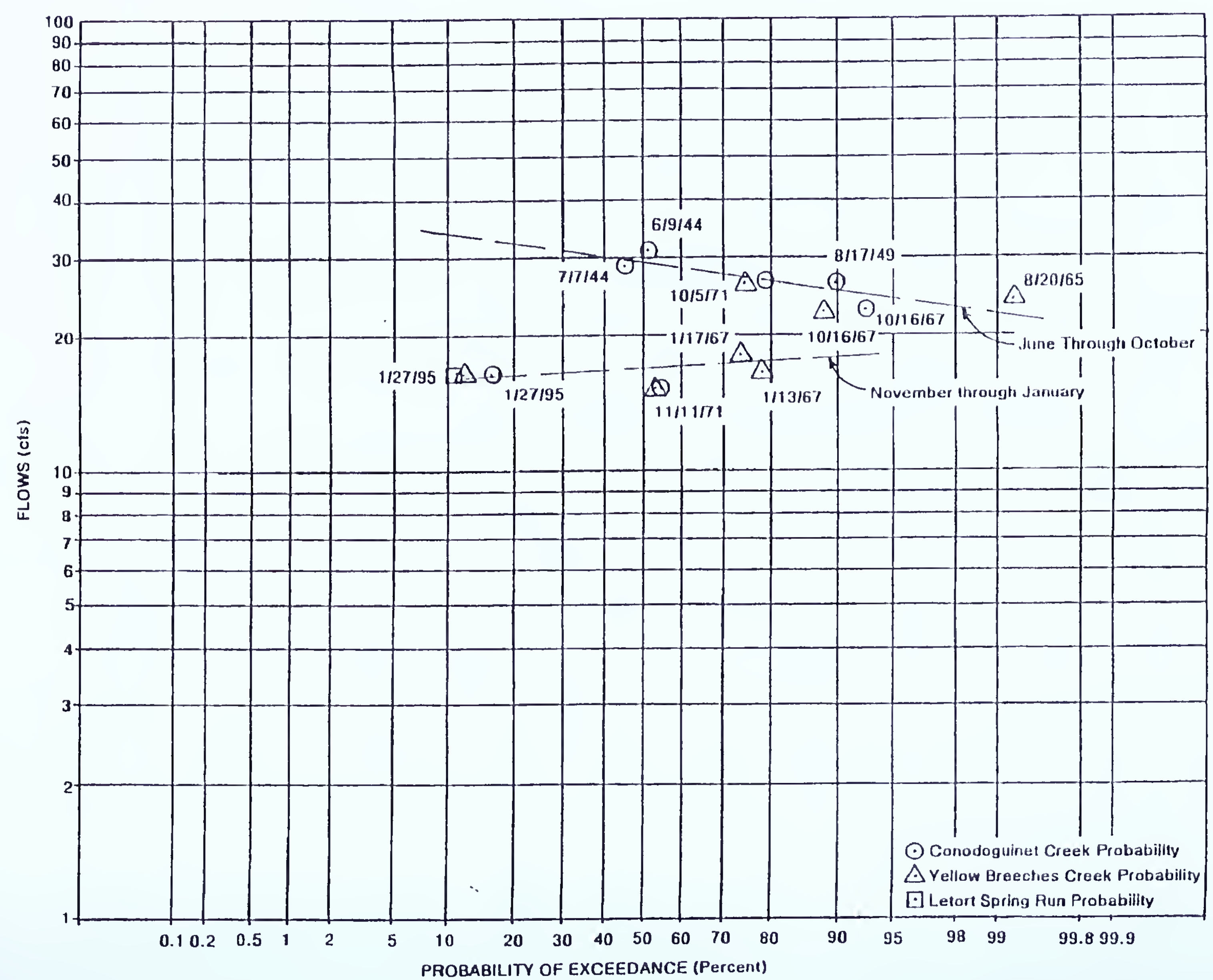


Figure D4. Big Spring Creek, Cumberland County, Flow Duration for Spring Flow

D11.0 STUDY SITE ON FALLING SPRING RUN, FRANKLIN COUNTY

There are two springs on the Falling Spring Run Watershed that are very close together and a short distance upstream from the study site. Flippo (1974) shows two spring flow measurements that are nearly equal. Because of the limited spring flow data available, additional spring flow measurements were made as part of three of the five data sets collected at the study site. The site and spring flow measurements are summarized in Table D4.

Table D4. Summary of Flow Measurements for Falling Spring Run

Measurement Date	Site Flow (cfs)	Spring Flow (cfs)	Letort Spring Run Flow (cfs)	Letort Probability (percent)
07/14/94	23.33	—	37	51
11/02/94	19.34	—	38	48
11/09/94	14.08	12.14	31	70
08/02/95	15.90	7.11	29	75
10/04/95	13.58	5.51	26	84

After several unsuccessful trials, the following procedure was used to determine the site flow duration curve.

- The site flows were plotted versus probability of exceedance of the corresponding gage flows for both Letort Spring Run near Carlisle and Conodoguinet Creek near Hogestown;
- The corresponding spring flows were plotted on the same graph, using the same probabilities;
- The spring flow measurements given by Flippo (1974) were plotted on the same graph, with the probability of exceedance determined from the concurrent Conodoguinet Creek flows, as shown in Figure D5. (Conodoguinet Creek was used to determine probability of exceedance for plotting these measurements, because the Letort Spring Run gage was not in operation at the time); and
- Curves were fitted to the site flows and spring flows by eye.

This plot shows the site measurements are reasonably consistent, with the exception of the July 14, 1994, measurement. That measurement was assumed to be incorrect, and was ignored for the purpose of developing hydrology. The spring flow measurements also fit reasonably well, with the exception of the November 9, 1994, and November 10, 1971, measurements reported by Flippo (1974).

Considering the natural complexity of the system and the scarcity of data to allow resolution of the complexity, this appears to be the best flow duration curve at the study site.

The necessary hydrology at the Falling Spring Run study site was determined in the same manner as for Trindle Spring Run.

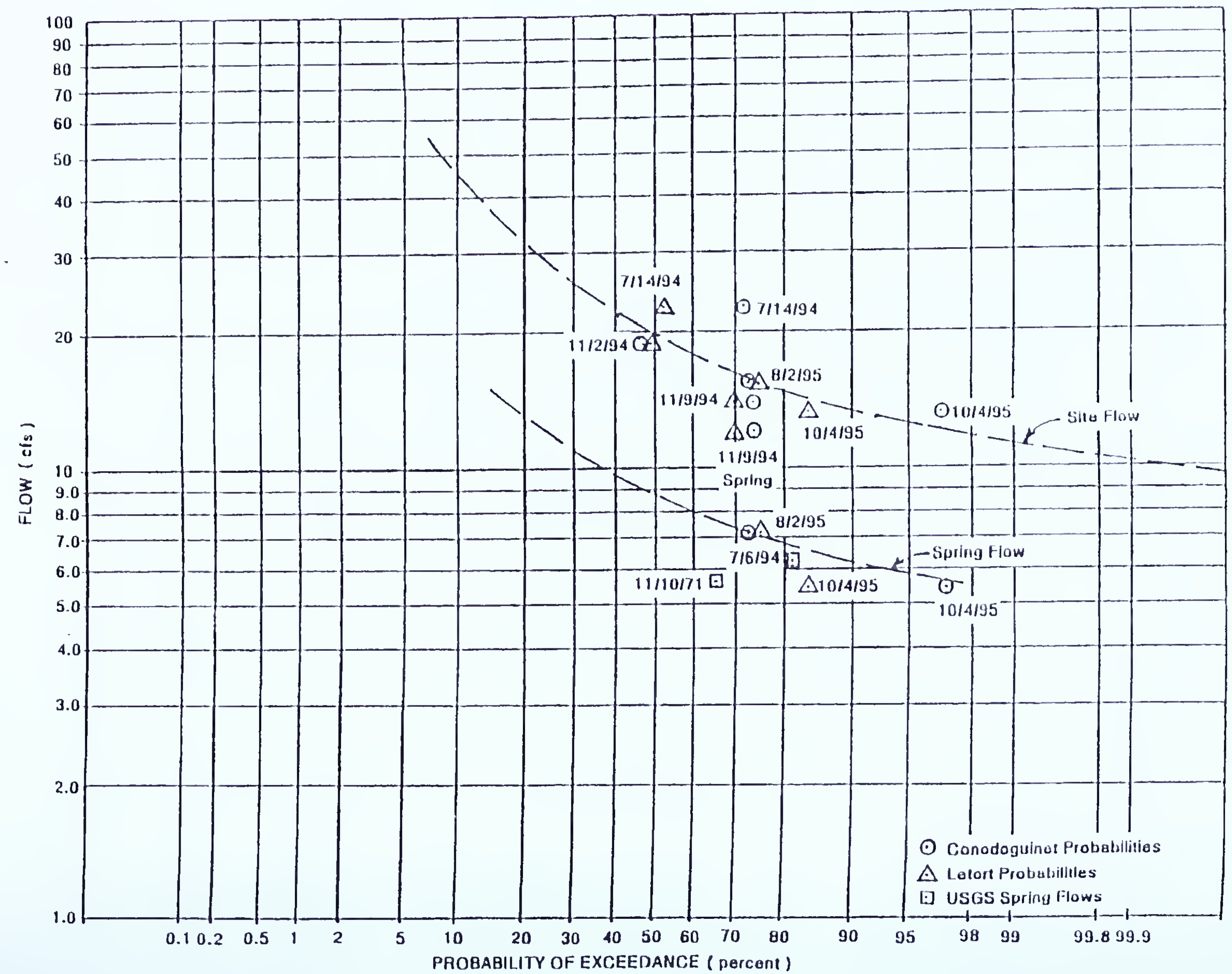


Figure D5. Falling Spring Run Flow Durations for Study Site and Springs

D12.0 STUDY SITES ON SPRING CREEK, CENTRE COUNTY

Five study segments are located in the Spring Creek Watershed. Cedar Run, and four segments on the main stem of Spring Creek. A drainage area ratio was applied to the Houserville gage data to estimate hydrology for Cedar Run and Spring Creek study sites 1 and 2. The hydrology for Spring Creek study sites 3 and 4 is complicated by springs and a WWTP flow.

USGS operates three continuous record stream gages on this watershed. Pertinent data for these gages are shown in Table D5.

Table D5. Gages in Spring Creek Watershed, Centre County

Gage Location	Period of Record	Period of Record Used	Drainage Area (sq. mi.)
Spring Creek at Houserville	1985-date	1985-94	58.5
Spring Creek near Axemann	1941-date	1985-94	87.2
Spring Creek at Milesburg	1967-date		142.0

The study site for Spring Creek segment 2 is located just upstream from the Houserville gage. The_study site for segment 4 is located just upstream from the Axemann gage. The University Area Joint Authority wastewater treatment plant discharges 6.98 cfs, as an annual average, just downstream from the Houserville gage. The treatment plant began operations in 1985.

Flippo (1974) shows flow measurements for nine springs in the Spring Creek Watershed. Five springs are located on the main stem of Spring Creek upstream of the Axemann gage (study sites 2, 3, and 4). The spring flow rates are summarized by study segment in Table D6. Only flow rates measured in November 1971 are shown, because that is the only consistent set of data.

Table D6. Spring Flow Rates of Spring Creek Watershed, Centre County
Source: Flippo (1974)

Study Segment	Spring Flow Rate Within Segment (gpm)		Spring Flow Rate Within Segment (cfs)	
	November 1971	Median	November 1971	Median
2	3,240	3,500	7.22	7.80
3	4,080	4,000	9.09	8.91
4	3,930*	4,000*	8.76*	8.91*
Downstream from study area	19,290	23,400	42.98	52.13

* No measurement for Bellefonte Fish Hatchery Spring in 1971 and no estimate of median flow; not included in the spring flow total for this reach.

The initial hydrology was based on data for the Milesburg gage. However, as shown in Table D6, more than half the total spring flow enters downstream from the Axemann gage and upstream from the Milesburg gage. Because the Milesburg gage is not representative of the flow regime in the study segments, only the Houserville and Axemann gages were used to estimate hydrology for the study sites.

Due to the effects of the WWTP discharge, only the period of record for the Axemann gage corresponding to the period of record for the Houserville gage was used in estimating flows for study sites 3 and 4, using the following procedure:

- The annual flow duration relationships for the Houserville and Axemann gages were tabulated for selected probabilities;
- The WWTP flow and the total spring flow between the Houserville and Axemann gages were added to the Houserville flows, and compared to the corresponding flows at the Axemann gage, which showed that:

  * For 95 and 90 percent probabilities of exceedance, the flow at Axemann was overestimated by small amounts;
  * For probabilities less than, or equal to 75 percent, the Axemann flows were underestimated by amounts that increased with increasing flow;

- The water balance at the Axemann gage was maintained by
  * Reducing the spring flow rate at the 95 percent probability of exceedance by about 6 percent to match the Axemann data; and
  * Assuming the differences between the observed and estimated flows at the Axemann gage for probabilities less than, or equal to, 75 percent were due to runoff from the intervening area and converting those differences to unit rates (csm);

- Flow duration relationships for study sites 3 and 4 were estimated by adding the Houserville flow, the average daily WWTP flow, the appropriate spring flow (Table D6), and the appropriate runoff, based on the runoff rates (csm) multiplied by the appropriate intervening area.

The necessary hydrology at study sites 3 and 4 was computed by: determining a flow at the Houserville gage; interpolating in the annual flow duration table for the Houserville gage to obtain the probability of exceedance for that flow; and interpolating in the annual flow duration table for the site at the same probability to determine the corresponding flow at the site.

D13.0 STUDY SITES ON PENNS CREEK, CENTRE COUNTY

Three study sites are located on Penns Creek. The first is a short distance downstream from Penn's Cave, which complicates the hydrology for these sites. Although the actual cave flow was not measured during this study, the cave flow was probably a large part of the measured flow at study site 1. The effect of the cave flow dissipates as the drainage area increases.

Flippo (1974) shows two flow measurements for Penn's Cave. The first measurement was made on August 13, 1944; the flow was 4,700 gpm (10.47 cfs). The second measurement was made on November 15, 1971; the flow was 3,420 gpm (7.62 cfs). He estimates the median flow rate as 4,000 gpm (8.9 cfs). The CDS flow at study site 1 was 9.17 cfs, slightly greater than the median cave flow. Efforts to contact the operators of the Penn's Cave recreation facility to obtain additional cave flow data were unsuccessful.

The annual flow duration at the study sites were initially estimated using flow data for the study sites and the flow duration table for the Penns Creek gage. The topographic and geologic maps show different topography and geology for segment 1, compared to the remainder of the watershed upstream

from the USGS gage on Penns Creek at Penns Creek. For that reason, the watershed upstream from the gage was divided into an area upstream from study site 1 and an area between study site 1 and the gage.

The cave flow at the time of the CDS measurement was estimated as greater than, or equal to, 4.2 cfs, but the corresponding upper bound could not be determined. Comparison of the two measurements of cave flow (Flippo, 1974) with the flows at the Penns Creek gage on the same date showed that the cave flow has been at least as great as 10.47 cfs. However, the probability of that flow could not be determined, because the cave flow measurements decrease with increasing flow at the gage.

The flow duration analysis for the Penns Creek gage resulted in 20 bins (21 boundary flow values) over the range between 100 percent and 10.73 percent probability of exceedance. The gage flow rates range from 21 cfs at 100 percent probability to 929 cfs at 10.73 percent probability. The maximum cave flow is greater than, or equal to, about 10.5 cfs, based on available measurements. The cave flow is less than 9.0 percent of the gage flow at 116 cfs, which is exceeded 74.59 percent of the time. Also, the drainage area above site 1 is about 5 percent of the drainage area at the gage. It appears that, for probabilities of exceedance less than 74.59 percent, most of the flow at the gage comes from runoff from the area between study site 1 and the gage. Also, for the drainage area above site 1, and for the same probabilities, most of the flow was assumed to come from the cave.

Several trials showed that a unique solution was not possible. Therefore, the cave flow and unit runoff rates for the drainage area upstream from site 1 were computed by trial and error to balance to the gage flow rates. The final trial assumed the cave flow was 6.5 cfs at 74.59 percent probability, which resulted in a unit runoff rate of 0.177 csm for the drainage area above site 1. The cave flows were constant at 6.5 cfs for probabilities greater than, or equal to, 74.59 percent, and the unit runoff rates were computed to balance the flows at the gage. For probabilities less than 74.59 percent, unit runoff rates for study site 1 were increased proportionately to the streamflow at the gage, and the cave flow rates were computed to balance the flows at the gage. The resulting cave flow is 11.1 cfs at 10.73 percent probability, which is only slightly greater than the maximum measured cave flow of 10.47 cfs (Flippo, 1974). This solution balances the observed flows at the gage within about 0.15 percent for all probability levels.

Subsequent studies during development of the regional hydrology (section 6.6.3) showed that data for the gage on Spring Creek at Houserville was more representative of the hydrology for the drainage area on Penns Creek underlain by limestone. About 10 percent of the total drainage area of the Penns Creek Watershed at the gage is underlain by limestone.

To synthesize flow duration at the study sites, the cave flows were determined as described above. The estimated cave flows were subtracted from the flows at the Penns Creek gage, to estimate the runoff from the freestone drainage area. For each study site and certain selected probabilities, the runoff from the area underlain by limestone rock was estimated by multiplying the corresponding flow value at the Houserville gage by the ratio of site drainage area underlain by limestone to drainage area at the Houserville gage. The runoff from the area underlain by freestone rock was estimated by multiplying the estimated runoff at the gage by the ratio of drainage area underlain by freestone to the drainage area at the Penns Creek gage. Then the respective flows from the cave, and runoff from limestone, and freestone were summed to estimate the flow at each study site.

D14.0 STUDY SITE ON HONEY CREEK, MIFFLIN COUNTY

Honey Creek is a tributary of Kishacoquillas Creek. The study site is located a short distance upstream from the confluence of Honey Creek with Kishacoquillas Creek, and just downstream from

Alexander Cavern. USGS operated a continuous record stream gage on Kishacoquillas Creek at Reedsville between 1940 to 1970, and 1984 to 1985. The gage was located just downstream from the mouth of Honey Creek.

The hydrology of Honey Creek is complicated by the fact that the cavern contributes a variable flow rate, and most of the drainage area upstream from the cavern is underlain by shale rock. Topographic maps show Honey Creek is perennial for much of its length upstream from the cavern, but becomes intermittent in the vicinity of the cavern. For that reason, Honey Creek was assumed to flow underground, for most of the range of flows, in the vicinity of the cavern. The topographic maps also show Kishacoquillas Creek upstream from the mouth of Honey Creek is a relatively large stream, and that streams in that part of the watershed are generally perennial.

Flippo (1974) shows a single measurement of the flow from the cavern, which was 14,600 gpm (32.5 cfs). He also estimates the median flow from Alexander Cavern as 14,000 gpm (32 cfs). The flow duration for the Reedsville gage shows flows as low as 13 cfs. If the cavern were the only source of flow at the gage at the time of the lowest flow, the low flow from the cavern must be less than, or equal to, 13 cfs. Because it is likely that the drainage area upstream from Honey Creek is contributing part of that low flow, the cavern flow was probably less than 13 cfs under this low flow condition. This reasoning implies the flow from the cavern decreases very rapidly with decreasing flows less than the median cavern flow. Therefore, the flow from the cavern appears to be highly variable and dependent on surface runoff from the watershed above the cave, and could not be easily estimated. For these reasons, it was assumed the study site hydrology was dependent primarily on runoff, and the effect of the cavern on storage and the time distribution of flow at the study site could be ignored.

The following procedure was used to develop flow duration at the site.

- The flow at the gage on the date of the completed data set measurement was partitioned into a flow from Honey Creek above the study site and a flow from the rest of the watershed. The resulting water balance equation is:

$$Q_G = Q_S + Q_R = r_S * A_S + r_R * A_R \qquad \text{(D3)}$$

where: Q_G = the observed flow at the gage;
Q_S = the flow from Honey Creek above the study site, including Alexander Cavern;
Q_R = the flow from the rest of the watershed above the gage;
r_S = a runoff rate from Honey Creek above the study site, including Alexander Cavern;
A_S = the drainage area above the study site;
r_R = the runoff rate from the remainder of the watershed;
A_R = the area of the remainder of the watershed;

- The flow rate at the study site was 18.68 cfs (0.20 csm) when the CDS was collected on February 10, 1995; the daily flow at the gage on the same date was 58 cfs (0.35 csm).
- The ratio of the runoff rate (csm) at the site to the runoff rate (csm) at the gage was computed as 0.56, and then rounded to 0.60, resulting in an effective runoff rate from the watershed upstream from the study site equal to 0.212 csm for the CDS measurement;
- The continuity equation was solved for the runoff rate from the rest of the watershed (0.532 csm);

- The annual flow duration curve at the site was computed from the flow duration at the gage by assuming the unit flow rates (esm) at the site were 60 percent of the corresponding unit flow rates for the rest of the watershed; and
- Flows at the site were determined from the site flow duration eurve by assuming the probability of exceedance at the site was the same as the probability of exceedance at the gage.

D15.0 STUDY SITE ON LONG HOLLOW RUN, MIFFLIN COUNTY

Long Hollow Run enters the Juniata River just east of Mt. Union. It is formed in a narrow, steep-sided valley, and the stream is formed on a narrow outcrop of limestone. About 20 pereent of the watershed is underlain by limestone rocks. This stream apparently is not a typical limestone stream.

Initially, hydrology was computed for this stream based on data for the USGS gage on Kishacoquillas Creek at Reedsville. The flow measurements showed the estimated flows were too high. Second, the annual flow duration at the site was computed using data for the USGS gage on the Frankstown Branch Juniata River at Williamsburg (L. Taylor, SRBC, oral communieation). Comparison of the estimated flows to the measured flows showed the former were too high by a factor of about 2. There is no obvious reason (e.g., split channel, sinkholes) for the flows at the study site to be so low (L. Baker and L. Boar, PFBC, oral communication, July 17, 1995). The measured flows at the study site seemed to fit the site flow duration eurve, based on data for the USGS gage on Dunning Creek at Belden. Dunning Creek at Belden has only small amounts of limestone (Shaw, 1974), and has very low flows compared to other limestone streams used in this study. During development of regional hydrology, Bixler Run at Loysville was seleeted instead, beeause the geology of the Bixler Run Watershed was similar to the geology of Long Hollow Run, and to simplify the delineation of hydrologic regions.

D16.0 STUDY SITES ON BOILING SPRING RUN, BLAIR COUNTY, AND POTTER CREEK, BEDFORD COUNTY

Boiling Spring Run flows north into Beaverdam Creek, which combines with other streams to form the Frankstown Branch Juniata River. The stream is located in a narrow valley between Dunning Mountain to the east and high hills to the west.

Initially, hydrology for Boiling Spring Run was based on data for the gage on Dunning Creek at Belden. However, as noted previously, there is little limestone on the Dunning Creek Watershed, and the measured flows were too high, compared to the annual flow duration based on Dunning Creek. Hydrology also was computed based on data for the gage on Frankstown Branch Juniata River at Williamsburg (L. Taylor, SRBC, oral eommunication). The resulting flow duration seemed reasonable, compared to the flow measurements. However, during the development of regional hydrology, Bixler Run at Loysville was selected instead. The reasons were the relative size of the Frankstown Branch and Boiling Spring Run Watersheds, the mixed geology of the Frankstown Branch Watershed, and the similarity of the geology of Bixler Run to the geology of Boiling Springs Run. Data for the Bixler Run gage was used in the impact analysis.

Potter Creek begins on the east side of Dunning Mountain and flows southeast into Yellow Creek, which is a tributary of the Raystown Branch Juniata River. The New Enterprise quadrangle map shows two springs in this watershed. Flippo (1974) does not show any data for these springs; therefore, they were assumed to be insignificant.

The hydrology for this study site was initially based on data for the USGS gage on the Frankstown Branch Juniata River at Williamsburg. However, the measurements for Potter Creek were too high, compared to the flow duration curve, so that gage was not used. The final hydrology for Potter Creek was based on data for the gage on Spring Creek at Houserville.

The differences in the hydrology of these two watersheds were considered in the regionalization of hydrology and impact analysis.

D17.0 STUDY SITES ON WAPWALLOPEN CREEK AND SALEM CREEK, LUZERNE COUNTY, AND MUGSER RUN AND EAST BRANCH RAVEN CREEK, COLUMBIA COUNTY

Wapwallopen Creek is affected by a water supply withdrawal from Crystal Lake, which is located in the headwaters of the watershed, and the return flows from the Mountaintop Joint Authority WWTP, which is located between study sites 2 and 3. The average daily water supply withdrawal is about 1.2 mgd (1.86 cfs) (S. Runkle, Pa. DEP, oral communication), and the average daily WWTP flow is 2.4 mgd (3.7 cfs). The minimum release from Crystal Lake is 0.378 cfs when the inflow exceeds that amount: otherwise the release equals the inflow. There also is an intermittent, small importation to Crystal Lake from the Delaware River Basin, which was considered insignificant.

USGS has operated a gage on Wapwallopen Creek at Wapwallopen since 1919. Initially, hydrology for Wapwallopen Creek was based on adjusting the observed flow duration at the gage for the effects of the water withdrawal and WWTP flows. However, it was determined this led to zero, and even negative flows for some months. The hydrology was revised to utilize the period of record prior to 1979, when the WWTP began operating. The flows for each study site were computed by drainage area ratio. The minimum release from Crystal Lake was ignored, but the WWTP flow was added to the flows for sites 3 and 4 to obtain the current hydrology.

The hydrology for Salem Creek, Mugser Run and East Branch Raven Creek were estimated by applying a drainage area ratio to the Wapwallopen Creek data for the period-of-record prior to 1979.

D18.0 STUDY SITE ON RED RUN, CAMBRIA COUNTY

Red Run is affected by a water supply withdrawal, which is 242,000 gpd (0.38 cfs). The natural hydrology was estimated by drainage area ratio, using the data for the USGS gage on Blacklick Creek at Josephine. The water supply withdrawal was subtracted from the natural hydrology to estimate the existing hydrology.

Appendix E

The Pennsylvania-Maryland Instream Flow Study Impact Analysis Program

E1.0 INTRODUCTION

The Pennsylvania/Maryland Instream Flow Study Impact Analysis Program is designed to estimate the potential impact of water withdrawals on trout habitat in cold-water streams. This analysis considers the study region in which the stream is found, the hydrology of the stream, the drainage area, the distance from the headwaters to the point of withdrawal, and the fish species composition in the stream. The program utilizes fishery habitat information, developed for specific study streams using the Instream Flow Incremental Methodology (IFIM). It is designed to predict the effects of a withdrawal on any stream that has not been studied, based on the average of the effects on studied streams in the same study region.

The computer program is written in Microsoft™ Excel 7.0 spreadsheet format. The minimum system requirements are an IBM™ compatible computer, with an 80486 processor; Microsoft™ Windows 95 operating system; and Microsoft™ Excel 5.0 program.

The Impact Analysis Program includes the detailed analysis and preliminary analysis programs, which are closely related. There are three main differences between these programs:

1. The detailed analysis program provides in-depth analysis of the effects of withdrawals on flows and habitat in terms of Renormalized Minimum Weighted Usable Area (RMWUA). The preliminary analysis program provides only a general overview of impacts of a proposed withdrawal over a range of potential passby flows. As a result, the output from the preliminary analysis program is much less detailed than the detailed analysis program.

2. The detailed analysis program allows the input of any passby flow, and the passby flows can vary seasonally. The preliminary analysis program automatically uses 13 different passby flows, ranging from 0 to 60 percent ADF, in 5 percent ADF increments. These flows cannot vary seasonally.

3. The two programs use different algorithms to compute average seasonal impacts to RMWUA.

There are a variety of ways to evaluate impacts to trout habitat using the various outputs produced from these programs. The detailed analysis program is designed to estimate average impacts on median monthly flow, or RMWUA, for a particular type of fishery on a monthly, seasonal, and annual basis. It also calculates changes in monthly, seasonal, and annual duration of flow and RMWUA. The program estimates the average impact on streamflow, or RMWUA, given the hydrology, drainage area, average daily flow, and species composition of a particular site, based on the streams studied in the specific class. The duration analyses are presented in tabular format but can also be graphed. The preliminary analysis program only estimates changes in seasonal and annual average RMWUA, and seasonal and annual median RMWUA, resulting from a given withdrawal combined with the preselected passby flows. Outputs such as duration analyses of the effects of withdrawal on flow and habitat are not computed in the preliminary analysis program. The abbreviated format of the preliminary analysis program allows a general evaluation of the effect of a wide range of passby flows for any given withdrawal, while reducing the run time necessary to analyze the same number of passby flows with the detailed analysis program.

The program also can perform analyses for other time steps (e.g., annual, daily) provided that hydrologic data file limits are not exceeded.

E2.0 DATA NEEDS AND CALCULATION METHODS

E2.1 Detailed Analysis Program

The detailed analysis program requires:

1. The natural median monthly flows for a period of years for the site from which the withdrawal is proposed (project stream). These flows should be synthesized using the regional hydrology procedures described in section 6.6.3.

2. The proposed withdrawal and passby flows for the project stream for each season. The proposed withdrawal and passby flows are entered in units of either cfs, csm, mgd, or percent ADF. The withdrawal and passby flow information can vary with season. One combination of withdrawal and passby flow must be entered for each season for each run.

3. Other required data such as the stream name, distance from the headwaters to the taking point, the study region, drainage area, and ADF at the taking point, and the trout species (brook, brown, or combined) to be considered.

4. The appropriate RMWUA versus flow tables, based on the study region. Tables for the Ridge and Valley Freestone, Ridge and Valley Limestone, and Unglaciated Plateau study regions are presently included in the program. Tables for the 12 study streams in the Piedmont Upland study region also are included.

The detailed analysis program:

1. Converts all median monthly flows to percent ADF.

2. Modifies the existing flow record for the effect of withdrawals and passby flows so that predictions of impacts on flow and habitat can be based on comparison of the existing (unimpacted by the proposed withdrawal) flow and habitat and the flow and habitat available as affected by the proposed withdrawal.

3. Converts the flows in the RMWUA versus flow tables for each study site in that class of streams to percent ADF, so that flow values for the project stream and each of the study streams can be directly related to each other.

4. Determines the stream segment class, based on length of stream.

5. Develops unimpacted and impacted median monthly RMWUA tables for each study stream, using the unimpacted and impacted median monthly flow tables for the project stream and the RMWUA versus flow relationships for each of the study streams.

6. Estimates the average monthly, seasonal, and annual RMWUA, both with and without the withdrawal, for each study stream, using the RMWUA values from the tables developed in step 5. Seasonal averages for each study stream are computed from all the individual monthly values in the period of record for each study stream. Thus, if there are three months in the season, and 50 years in the period of record, the average seasonal RMWUA for that particular season would be calculated using 150 values.

7. Estimates the average change and average percent change in RMWUA for each month, season, and year, for each study stream in the appropriate class of streams, based on the flows for the project stream.

8. Computes the average monthly, seasonal, and annual impact of the withdrawal on RMWUA for the project stream by averaging all the individual monthly, seasonal and annual outputs for all the study streams in the stream class (steps 5 and 6 above) across years and then across streams (stream variation method). Standard deviations and 95 percent confidence intervals also are calculated for the average data sets. For example, if there are 19 study streams in a particular class of streams, the average impact to RMWUA in March would be calculated from the average of the 19 average March impacts, one from each of the 19 study streams, and the sample size used in the confidence interval calculation would be 19.

9. Computes the average monthly, seasonal, and annual impact of the withdrawal on RMWUA for the project stream by averaging all the individual monthly, seasonal and annual outputs for all the study streams in the stream class (steps 5 and 6 above) across streams and then across years (yearly variation method). Standard deviations and 95 percent confidence intervals also are calculated for this case. The sample size used to compute standard deviations and confidence intervals is equal to the number of years of record used to develop the hydrology for the stream.

10. Develops a table of average median monthly RMWUAs by averaging all the corresponding individual median monthly values from the individual RMWUA tables for each study stream in the stream class. The size of the resulting table of RMWUAs will be 12 months times the number of years in the estimated hydrology for the project stream.

11. Computes duration analyses of flow and RMWUA with and without the withdrawal, using the table described in step 8. Monthly duration analyses use all the monthly values for each month in the period of record. Seasonal duration analyses use all the monthly values from each season. Thus, if there are three months in a season and 20 years in the period of record, 60 values would be used in the seasonal duration analysis. Annual duration analyses use all the monthly values in the table. Thus, if there are 20 years in the period of record, 240 values would be used in the annual duration analysis.

The differences between the stream variation method and the yearly variation method generally appear in the values of standard deviations and confidence limits. The averages should be similar.

E2.2 Preliminary Analysis Program

Data entry for the preliminary analysis program is identical to that of the detailed analysis program, except that passby flows are not entered. The program automatically estimates the impacts of the proposed withdrawal with 13 preset passby flows. The program performs the following data manipulations and calculations:

1. Develops unimpacted and impacted median monthly RMWUA tables for each study stream, using the same process described in steps 1-4 for the detailed analysis program.

2. Estimates the average seasonal and average annual RMWUA, both with and without the withdrawal, for each study stream, using the RMWUA values from the tables developed in step 1. First, the RMWUA values for the months in a season are averaged, resulting in one

seasonal value for each year. Then, the seasonal averages for each year for each study stream are averaged across years to obtain a seasonal average for each study stream. Thus, if there are three months in a season, three values are averaged for each year, for each stream, to obtain a seasonal average for the year. Then, if there are 50 years in the period of record, 50 values (one seasonal value per year) are averaged to derive the seasonal average. This differs from the algorithm used to derive seasonal averages in the detailed analysis program. (See step 5 above for the detailed analysis program.) The difference is that the preliminary analysis program first averages the months in each season in each year to derive seasonal averages for each year. It then averages each of these seasonal values for the entire period of record. The detailed analysis program skips this first step. Consequently, the results may be slightly different.

3. Estimates the average percent change in seasonal and annual RMWUA for each study stream in the appropriate class of streams using the flows from the project stream.

4. Estimates the average seasonal and annual impact of the withdrawal on RMWUA for the project stream by averaging all the individual seasonal and annual outputs from all the study streams in the stream class (steps 2 and 3 above).

5. Estimates the median seasonal and annual RMWUA, with and without the withdrawal, and the absolute and percentage change in median RMWUA. The same process described in steps 2-4 above is used, except that the median of the RMWUA values in each year in the period of record is determined for each study stream, and not the average as in step 2. This is a different algorithm than is used in the detailed analysis program, where the median values can be derived from the duration analysis described in steps 8 and 9 of the detailed analysis program. As a result, the answers will likely be slightly different from those calculated using the detailed analysis program.

E3.0 PROGRAM INSTALLATION

This program includes two files, **PA-MD Instream Flow Study.XLS** and **Output.XLT**, which are distributed on two 3.5 inch floppy diskettes, and requires at least 15 MB of free hard drive space. The two files must be installed on the hard drive in the Excel directory in a folder named **PA-MD IF Study.** If the folder does not already exist, it will be created automatically. The files are compressed, and will automatically decompress to the folders listed above.

To install, place floppy disk 1 into the computer, access the file on the disk, double click on the file Pa-Md IF STUDY, and follow the instructions on the screen. Do not change the **unzip to** location during installation, because the file is programmed to unzip to the correct folders.

E4.0 PROGRAM LAUNCH, INPUT, OUTPUT, AND OPERATION

To launch the program, open the file **C:\EXCEL\Pa-Md IF STUDY\PA-MD Instream Flow Study.XLS**. The program will open to the Main Menu for the Detailed Analysis and Preliminary Analysis Programs, shown in Figure E1. There are four buttons on this screen. The button labeled "Info: Getting Started" leads to an introductory screen that provides information regarding use of the program. The "Detailed Analysis Program" or "Preliminary Analysis Program" buttons lead to the respective programs.

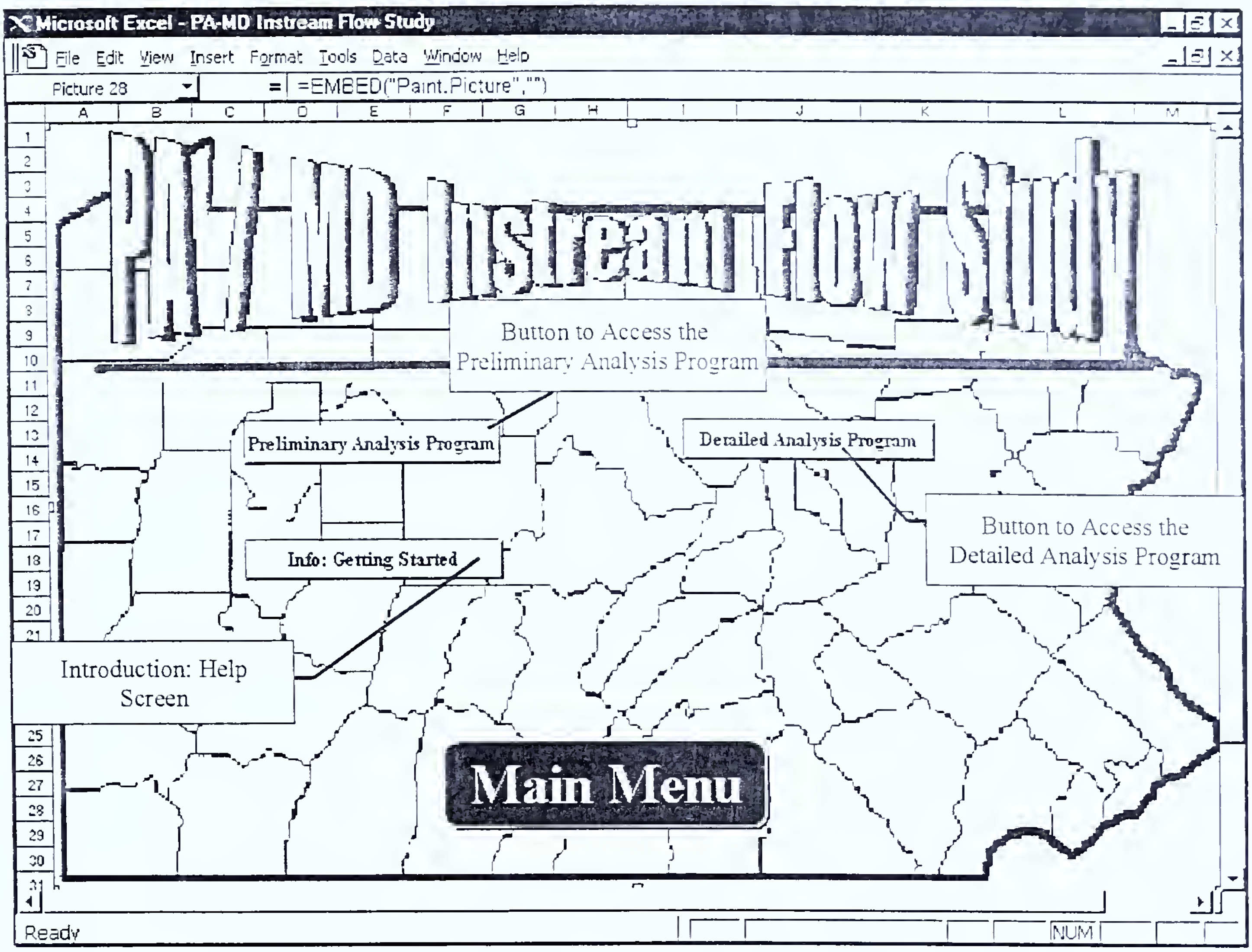


Figure E1. Instream Flow Impact Analysis Program Main Menu

E4.1 Detailed Analysis Program

E4.1.1 Input data

To access the Detailed Analysis Program, press the Detailed Analysis Program button on the Main Menu (Figure E1). The Streamflow Data Form, shown in Figure E2, appears automatically. Enter the median monthly flow time series for the study site in this table If hydrologic data has been previously entered in the program, press the Clear Monthly Medians button to clear the data file, before entering new data. Hydrologic data can be entered either from the keyboard, or by pasting data from a previously computed file, but must be in units of cubic feet per second (cfs). Be sure to copy only the years and flow values, without any headings or other description. The analysis programs can handle up to 75 years of hydrologic data.

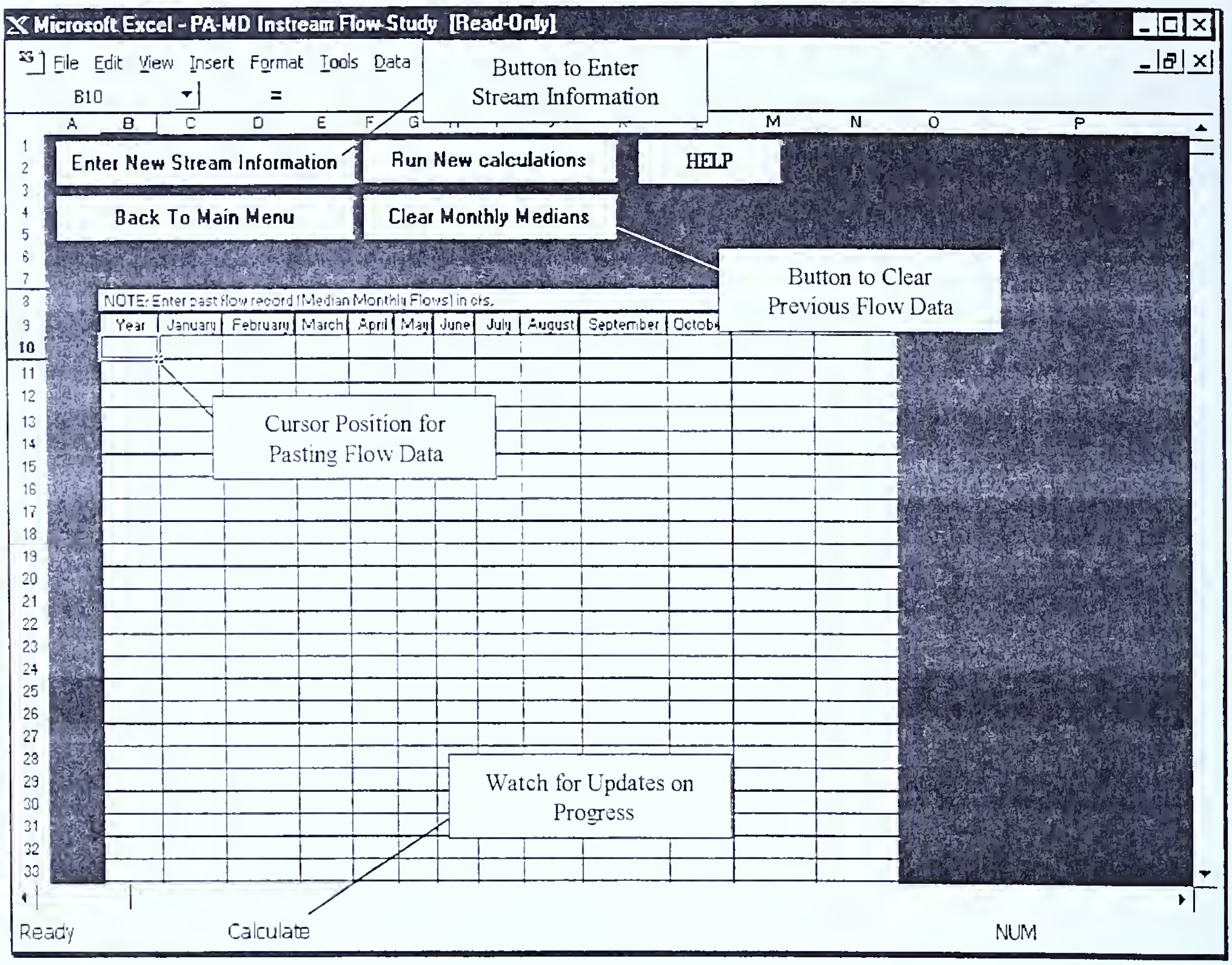


Figure E2. Streamflow Data Form

When the hydrologic data have been entered, press the Enter New Stream Information button to display the Stream Information dialog box shown in Figure E3. This dialog box is used to enter information regarding the project stream. Use the TAB key to scroll between data fields.

Enter the name of the project stream in the first data field. In this dialog box there are three list boxes that allow the user to pick the relevant information from a previously defined list, rather than typing it into a box. The Distance from Headwaters to Taking Point is selected in the first list box. The distance is divided into 5-mile increments, so that the options are 0-5.0 miles, 5.1-10.0 miles, 10.1-15.0 miles, 15.1-20.0 miles, and greater than 20.1 miles. Simply select the appropriate category for the project stream from the list. Because there are no study streams longer than 20.0 mi. at this time, selection of that category results in an error message.

The Study Region is selected from the next list box. The study region may be either Ridge and Valley Limestone, Ridge and Valley Freestone, or Unglaciated Plateau. Although RMWUA data for the Piedmont study streams are included in the data file, studies are incomplete, and hydrology is not provided at this time. Therefore, the Piedmont study stream data should not be utilized at this time.

The trout species and type of population present in the project stream are selected in the third list box. The following options are allowed: wild brook trout; wild brown trout; wild combined brook and brown trout; stocked adult brook trout; stocked adult brown trout; stocked adult combined brook and brown trout; stocked fingerling brook trout; stocked fingerling brown trout; and stocked

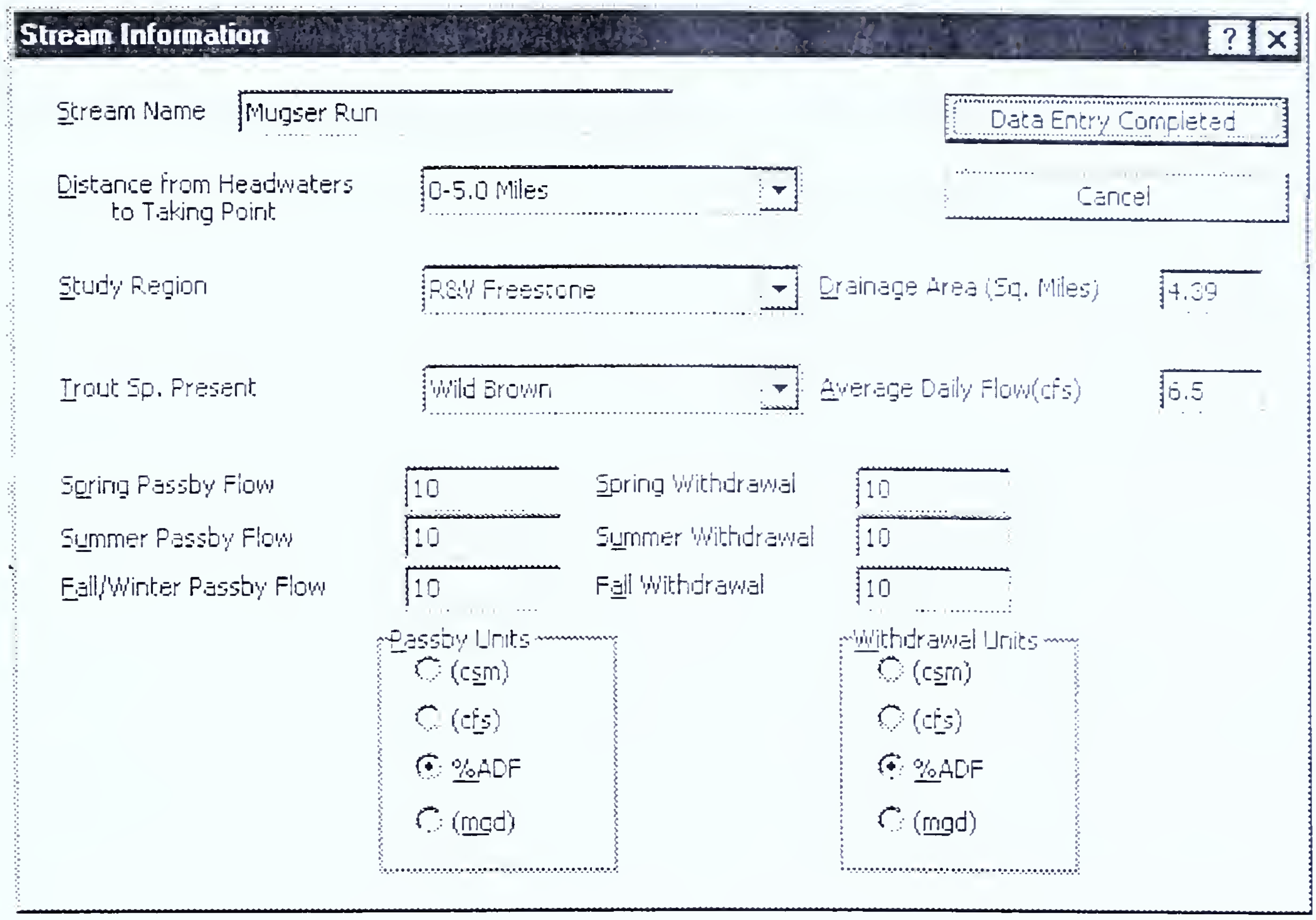


Figure E3. Detailed Analysis Program Stream Information Dialog Box

fingerling combined brook and brown trout. The differences in the evaluation of wild and stocked populations are described in section 6.6.2.1.

After completing the three list boxes, enter the drainage area at the site of the withdrawal, the corresponding average daily flow, and the passby and withdrawal flow rates for each season, in the respective boxes. Then press the box for the appropriate units for both withdrawal and passby flows. Note that the average daily flow must be entered in units of cfs, but the withdrawal and passby flows can be entered in several alternative units. The program automatically converts all flow data to percent ADF.

The Cancel button on this dialog box clears all new stream information and returns control to the flow data input screen (Figure E2).

Once this information is entered, press the Data Entry Completed button to return to the streamflow data screen (Figure E2). Then press the Run New Calculations button at the top of that screen to run the detailed analysis program. This program may take several minutes to compute the results depending on the computer's processor speed, and the number of streams in the class. Check the status bar at the bottom left corner to see the progress. Experience shows that with a Pentium 133 mhz processor, the computations require about 45 seconds for each combination of withdrawal and passby flow.

E4.1.2 Output table structure and interpretation

When the computations are complete, the output table will be displayed. The table includes buttons that control program operation, the input data, and the output data. The output data includes three main sections, the stream variation section, the duration analysis section, and the yearly variation section, as shown schematically in Figure E4. The first and third sections summarize the RMWUA computations for the respective methods described in the Data Needs and Computations section of this appendix. The duration analysis section summarizes duration analyses of flow and RMWUA, which do not depend on the method used to summarize the computations.

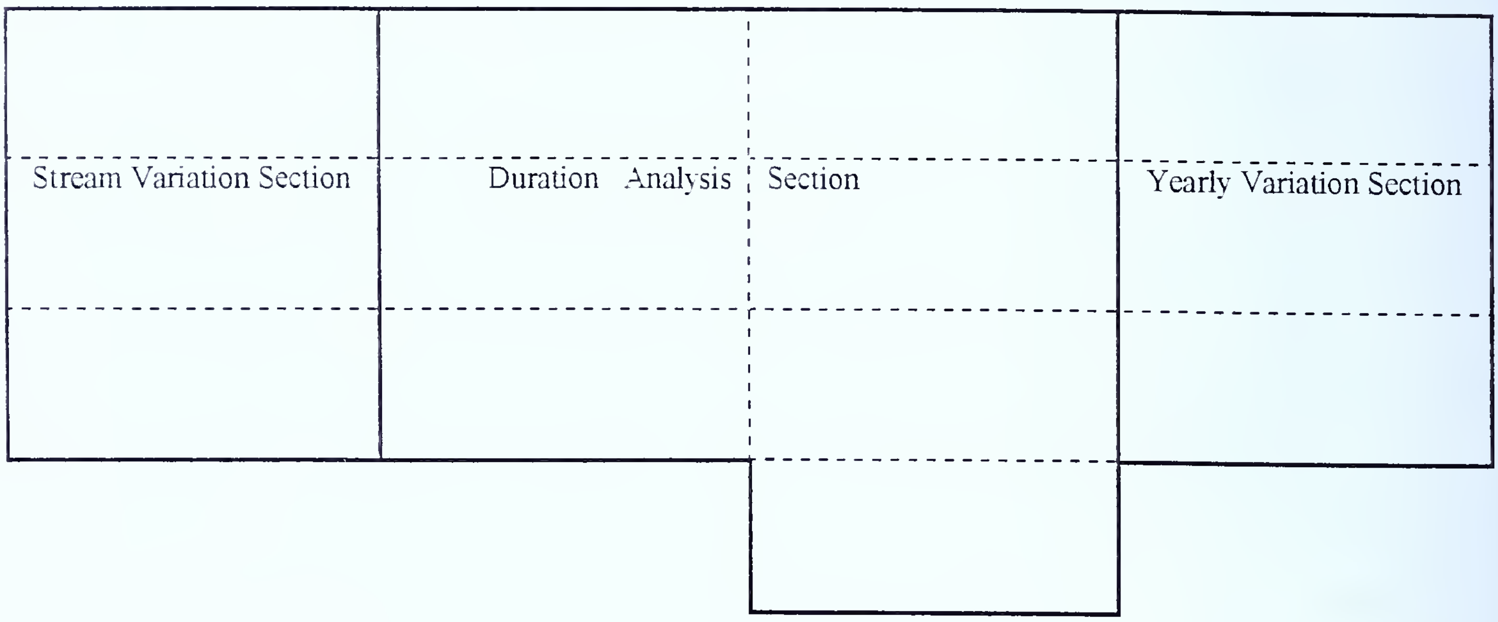
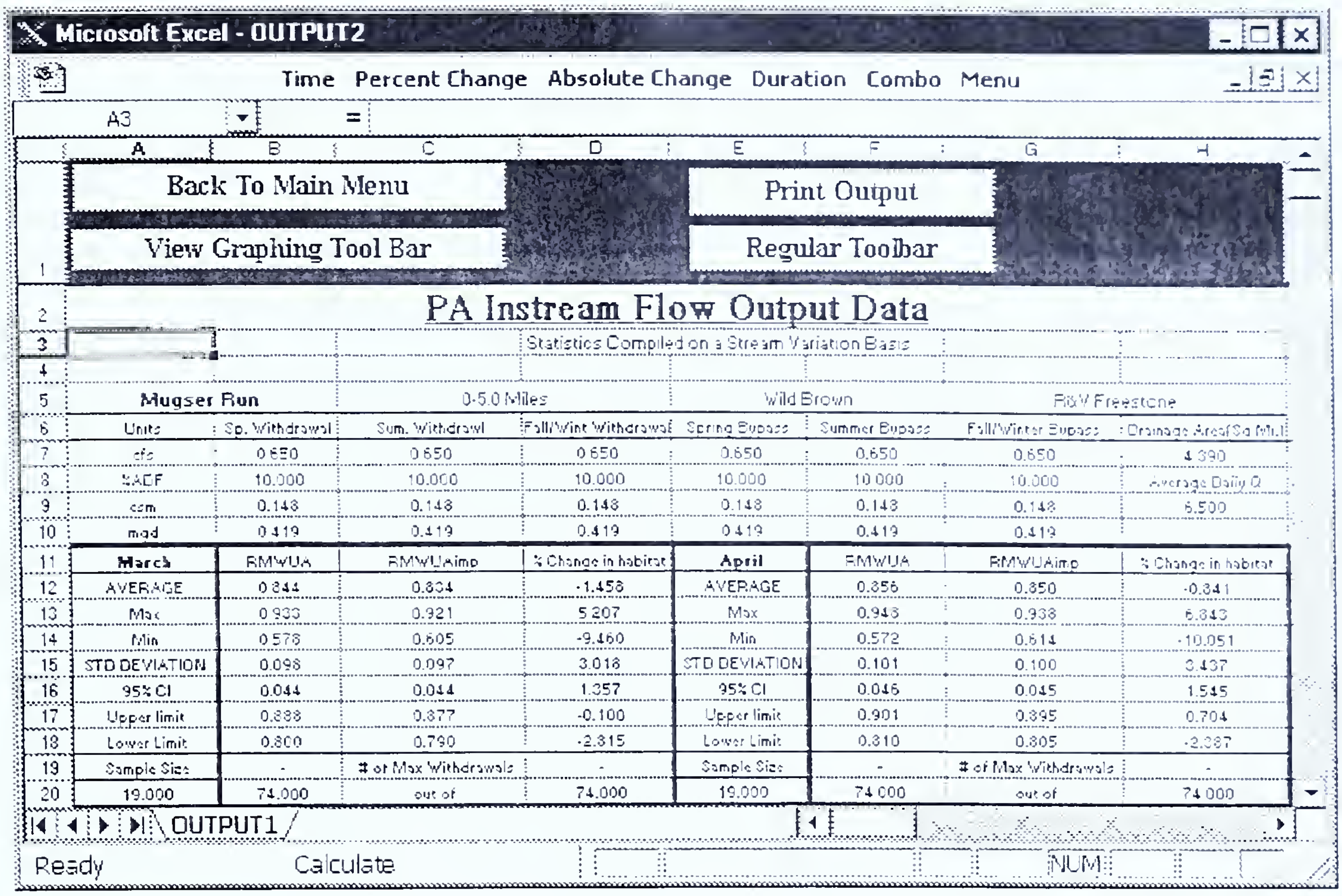


Figure E4. Schematic of Output Table Sections

The stream variation and the yearly variation sections of the output table are essentially identical in form. The first six lines of output show the input data, including seasonal withdrawals and passby flows. The remainder of these sections is divided into groups of 10 lines for each month, and the table is split vertically so that two months are included in each group of 10 lines. The first month shown is March, because it is the beginning of the spring season.

A sample of the monthly part of the stream variation section of the output table is shown in Figure E5. A summary explanation of the monthly output data included in this part of the table is shown in Table E1. Similar seasonal, combined monthly and annual statistics also are provided.



PA Instream Flow Output Data

Statistics Compiled on a Stream Variation Basis

Mugser Run		0-5.0 Miles		Wild Brown		R&V Freestone	
Units	Sp. Withdrawl	Sum. Withdrawl	Fall/Wint Withdrawal	Spring Bypass	Summer Bypass	Fall/Winter Bypass	Drainage Area(Sq Mi.)
cfs	0.650	0.650	0.650	0.650	0.650	0.650	4.390
%ADF	10.000	10.000	10.000	10.000	10.000	10.000	Average Daily Q
csm	0.148	0.148	0.148	0.148	0.148	0.148	6.500
mgd	0.419	0.419	0.419	0.419	0.419	0.419	
March	RMWUA	RMWUAimp	% Change in habitat	**April**	RMWUA	RMWUAimp	% Change in habitat
AVERAGE	0.844	0.834	-1.458	AVERAGE	0.856	0.850	-0.841
Max	0.933	0.921	5.207	Max	0.948	0.938	6.843
Min	0.578	0.605	-9.460	Min	0.572	0.614	-10.051
STD DEVIATION	0.098	0.097	3.018	STD DEVIATION	0.101	0.100	3.437
95% CI	0.044	0.044	1.357	95% CI	0.046	0.045	1.545
Upper limit	0.888	0.877	-0.100	Upper limit	0.901	0.895	0.704
Lower Limit	0.800	0.790	-2.815	Lower Limit	0.810	0.805	-2.387
Sample Size	-	# of Max Withdrawals	-	Sample Size	-	# of Max Withdrawals	-
19.000	74.000	out of	74.000	19.000	74.000	out of	74.000

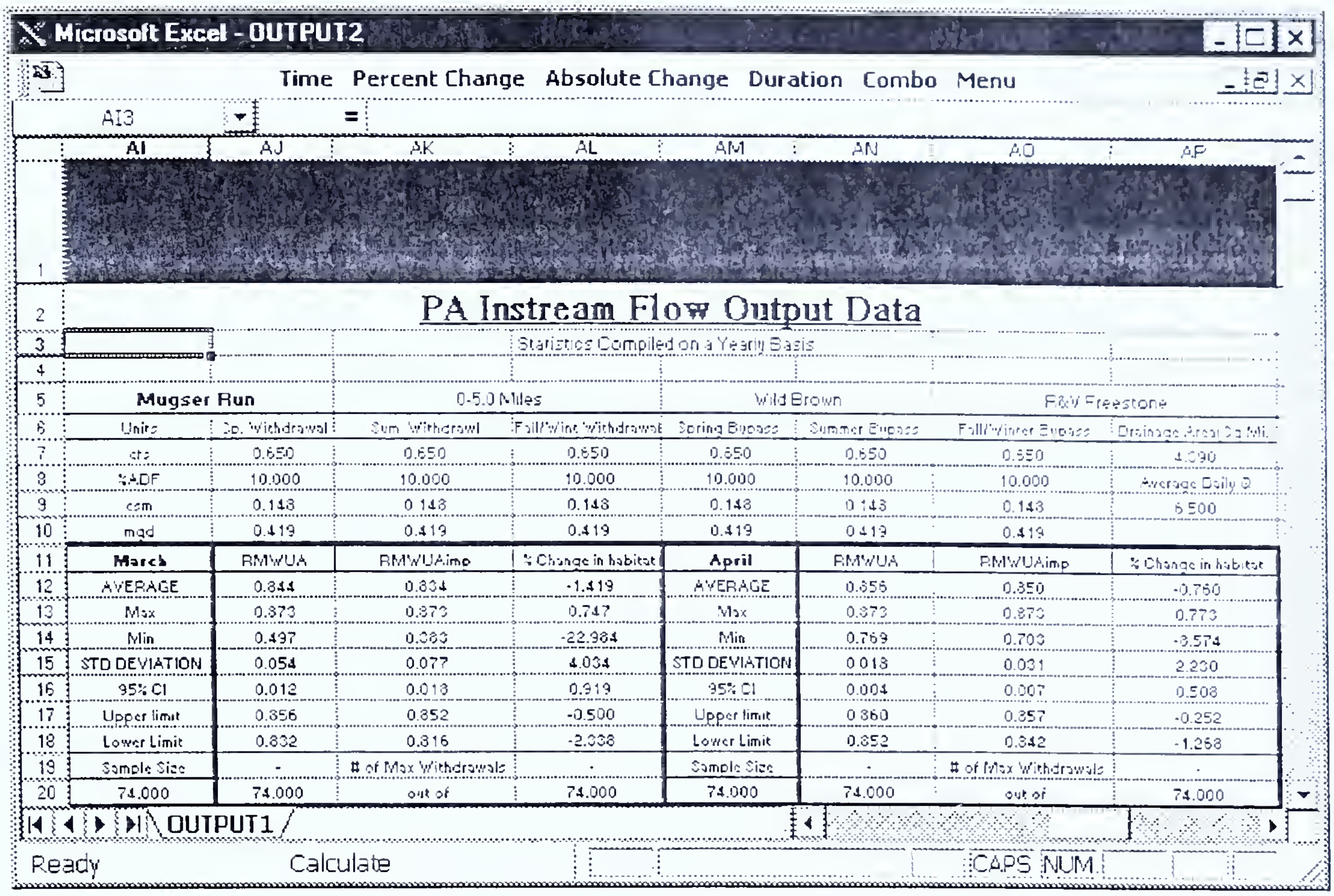
Figure E5. Sample Detailed Analysis Program Output Table, Stream Variation Method

Table E1. Explanation of Monthly RMWUA Statistics, Stream Variation Method

[Month]	RMWUA (Natural Conditions)	RMWUAimp (Impacted Conditions)	%Change in Habitat
AVERAGE	Average of average habitat (RMWUA) values, one for each study stream, for month shown	Average of average habitat (RMWUAimp) values, one for each study stream, for month shown	Average of values described below*
Max	Maximum of average habitat (RMWUA) values, one for each study stream, for month shown	Maximum of average habitat (RMWUAimp) values, one for each study stream, for month shown	Maximum of values described below*
Min	Minimum of average habitat (RMWUA) values, one for each study stream, for month shown	Minimum of average habitat (RMWUAimp) values, one for each study stream, for month shown	Minimum of values described below*
STD DEVIATION	Standard deviation of average habitat (RMWUA) values, one for each study stream, for month shown	Standard deviation of average habitat (RMWUAimp) values, one for each study stream, for month shown	Standard Deviation of values described below*
95% CI	95^{th} Percentile Confidence Interval of the average habitat RMWUA values, one for each study stream, for month shown	95^{th} Percentile Confidence Interval of the average habitat RMWUA values, one for each study stream, for month shown	95^{th} Percentile Confidence Interval of percent change in habitat.
Upper Limit	Upper limit of the 95% confidence band	Upper limit of the 95% confidence band	Upper limit of the 95% confidence band
Lower Limit	Lower limit of the 95% confidence band	Lower limit of the 95% confidence band	Lower limit of the 95% confidence band
Sample Size	# of Max Withdrawals		
Number of study streams in region	Number of years over period-of-record in which entire withdrawal is available in month shown	out of	Number of years over period-of-record in which month shown occurs

*For a given month, for each study stream, the model calculates a percent change in habitat value for each year of record. An average for the period-of-record is then calculated for each stream by averaging the yearly values. These averages across years are averaged across streams, and the result is shown in the first row. The maximum, minimum, standard deviation, and confidence interval across streams are shown in the appropriate rows.

A sample of the monthly part of the yearly variation section of the output table is shown in Figure E6. A summary of the output data included in the yearly variation section is shown in Table E2. Similar statistics are provided for the spring, summer, and fall/winter seasons and for combined monthly and yearly periods.



Microsoft Excel - OUTPUT2

Time Percent Change Absolute Change Duration Combo Menu

AI3 =

	AI	AJ	AK	AL	AM	AN	AO	AP
1								
2	PA Instream Flow Output Data							
3			Statistics Compiled on a Yearly Basis					
4								
5	Mugser Run		0-5.0 Miles		Wild Brown		R&V Freestone	
6	Units	Sp. Withdrawal	Sum. Withdrawl	Fall/Wint Withdrawal	Spring Bypass	Summer Bypass	Fall/Winter Bypass	Drainage Area Sq Mi.
7	cfs	0.650	0.650	0.650	0.650	0.650	0.650	4.090
8	%ADF	10.000	10.000	10.000	10.000	10.000	10.000	Average Daily Q
9	csm	0.148	0.148	0.148	0.148	0.148	0.143	6.500
10	mgd	0.419	0.419	0.419	0.419	0.419	0.419	
11	March	RMWUA	RMWUAimp	% Change in habitat	April	RMWUA	RMWUAimp	% Change in habitat
12	AVERAGE	0.844	0.834	-1.419	AVERAGE	0.856	0.850	-0.760
13	Max	0.873	0.873	0.747	Max	0.873	0.870	0.773
14	Min	0.497	0.383	-22.984	Min	0.769	0.703	-8.574
15	STD DEVIATION	0.054	0.077	4.034	STD DEVIATION	0.018	0.031	2.230
16	95% CI	0.012	0.018	0.919	95% CI	0.004	0.007	0.508
17	Upper limit	0.856	0.852	-0.500	Upper limit	0.860	0.857	-0.252
18	Lower Limit	0.832	0.816	-2.338	Lower Limit	0.852	0.842	-1.268
19	Sample Size	-	# of Max Withdrawals	-	Sample Size	-	# of Max Withdrawals	-
20	74.000	74.000	out of	74.000	74.000	74.000	out of	74.000

OUTPUT1

Ready Calculate CAPS NUM

Figure E6. Sample Detailed Analysis Program Output Table, Yearly Variation Method

Table E2. Explanation of Monthly RMWUA Statistics, Yearly Variation Method

[Month]	RMWUA (Normal Conditions)	RMWUAimp (Impacted Conditions)	% Change in Habitat
AVERAGE	Average of average habitat (RMWUA) values, one for each year in period-of-record, for month shown	Average of average habitat (RMWUAimp) values, one for each year in period-of-record, for month shown	Average of values described below*
Max	Maximum of average habitat (RMWUA) values, one for each year in period-of-record, for month shown	Maximum of average habitat (RMWUAimp) values, one for each year in period-of-record, for month shown	Maximum of values described below*
Min	Minimum of average habitat (RMWUA) values, one for each year in period-of-record, for month shown	Minimum of average habitat (RMWUAimp) values, one for each year in period-of-record, for month shown	Minimum of values described below*
STD DEVIATION	Standard deviation of average habitat (RMWUA) values, one for each year in period-of-record, for month shown	Standard deviation of average habitat (RMWUAimp) values, one for each year in period-of-record, for month shown	Standard Deviation of values described below*
95% CI	95^{th} Percentile Confidence Interval of average habitat (RMWUA) values, one for each year in period-of-record, for	95^{th} Percentile Confidence Interval of average habitat (RMWUAimp) values, one for each year in period-of-record,	95^{th} Percentile Confidence Interval of values described below*
Upper Limit	Upper Limit of the 95% confidence band	Upper Limit of the 95% confidence band	Upper Limit of the 95% confidence band
Lower Limit	Lower limit of the 95% confidence band	Lower limit of the 95% confidence band	Lower limit of the 95% confidence band
Sample Size	# of Max Withdrawals		
Number of times month shown occurs in period-of-record	Number of years over period-of-record in which entire withdrawal is available in month shown	out of	Number of years month shown occurs in period-of-record

*For a given month, for each year in the period-of-record, the average natural and average impacted RMWUA values are calculated from the monthly natural and impacted RMWUA values for each study stream. A percent change in habitat value is then calculated for each year from the difference between the average natural and average impacted RMWUA values. The average, maximum, minimum, standard deviation, confidence interval, and limits of confidence band of those yearly values are then reported in the output in the respective rows.

The duration analysis section of the output table includes five parts, as shown schematically in Figure E7. Each column of data is calculated independently; thus, the flow duration can not be estimated from the RMWUA duration, and vice versa.

Duration Table of Unimpacted and Impacted Monthly Median Flows	Duration Table of Percent Loss in RMWUA (Monthly, Seasonal, and Annual) (Figure E8)
Duration Table of Unimpacted and Impacted Monthly RMWUAs	Duration Table of Actual Loss in RMWUA (Monthly, Seasonal, and Annual)
Seasonal and Annual Duration Table of Unimpacted and Impacted Flows and RMWUA	Duration Table of Percent Loss in Flow (Monthly, Seasonal, and Annual)
	Duration Table of Actual Loss in Flow (Monthly, Seasonal, and Annual)

Figure E7. Schematic of Duration Analysis Section of Output Table

A sample RMWUA duration table is shown in Figure E8. The other duration tables have a similar form. Each section of the duration table is printed on a separate page. Each page includes one subsection shown in Figure E7, and the pages are printed in column order.

Microsoft Excel - OUTPUT2

Time Percent Change Absolute Change Duration Combo Menu

Percent Loss in RMWUA (Monthly)

Percent Exceedance	March	April	May	June	July	August	September	October	November	December	January	February
100	22.984	8.574	19.653	31.104	33.077	33.077	33.077	33.087	33.087	33.087	31.145	33.087
99	16.724	7.796	18.469	28.231	33.077	31.543	32.044	33.087	33.087	33.087	30.387	27.794
98	12.493	7.298	16.979	27.168	32.110	30.976	31.346	32.155	33.087	31.657	27.519	25.086
95	9.890	6.391	15.074	26.952	30.975	30.976	30.401	31.145	31.325	28.377	13.914	23.404
90	6.726	3.835	10.244	23.833	30.092	28.984	29.659	30.107	29.835	22.089	16.954	18.380
80	1.862	0.648	7.479	21.838	26.509	25.040	24.928	25.836	20.319	13.077	15.018	12.672
70	0.002	0.019	4.599	18.446	24.060	22.099	21.926	20.336	14.420	10.101	12.161	11.040
60	0.000	0.000	2.369	15.298	22.065	19.853	16.759	16.488	10.961	7.657	10.631	8.846
50	-0.024	-0.022	0.019	13.440	19.519	18.994	12.616	15.340	8.820	6.710	9.855	6.935
40	-0.120	-0.096	0.000	10.859	16.323	15.715	11.223	13.305	6.852	5.449	6.483	6.127
30	-0.393	-0.221	-0.112	7.499	12.709	10.843	6.141	9.649	5.541	3.965	5.221	5.112
20	-0.483	-0.444	-0.373	4.488	9.195	5.609	3.100	5.954	4.002	3.150	3.498	3.199
10	-0.652	-0.661	-0.679	-0.039	5.224	0.036	0.000	0.253	3.217	0.475	1.753	1.041
5	-0.692	-0.735	-0.737	-0.639	0.000	0.000	0.000	0.000	0.174	0.126	0.813	0.377
2	-0.734	-0.769	-0.771	-0.690	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0	-0.747	-0.773	-0.773	-0.697	0.000	0.000	0.000	0.000	0.000	0.000	-0.021	0.000

Percent Loss in RMWUA (Seasonal)

Percent Exceedance	Spring	Summer	Fall/Winter	Annual
100	31.104	33.077	33.087	33.087
99	27.168	33.077	33.087	33.077
98	23.833	31.374	32.487	31.145
95	22.005	30.976	30.107	30.092

OUTPUT1

Ready Calculate CAPS NUM

Figure E8. Sample Duration Analysis Table

4.1.3 Graphics

The output table screens (Figures E5 and E6) automatically show the graphics menu tool bar. The output can be displayed graphically by pressing one of the graphics menu shortcuts.

An expanded view of the graphics menu tool bar is shown in Figure E9. When any of the buttons (except Menu) is selected, the dropdown box shown in Figure E9 under "Percent Change" appears, which allows selection of graphs of RMWUA or flow. The "Percent Change", "Absolute Change", and "Duration" menu choices also provide options (not shown here) to graph either monthly, seasonal, or annual data. The "Time" button graphs the appropriate time series of absolute change in RMWUA or flow caused by the withdrawal. The "Percent Change" button graphs the difference in RMWUA, or flow, expressed as a percentage of the unimpacted values for a specified period, across years, versus probability of exceedance in percent. The specified period may be a particular month, or season, or all the annual values. The "Absolute Change" button produces the same graphs for the absolute change in RMWUA, or flow. The "Duration" button graphs the probability of exceedance (duration) of median monthly RMWUA, or flow, for the entire record used, for both unimpacted and impacted conditions. The Combo button combines similar graphs for different combinations of withdrawal and passby flow. Simply press the appropriate menu item to create a graph of that variable on a separate output sheet.

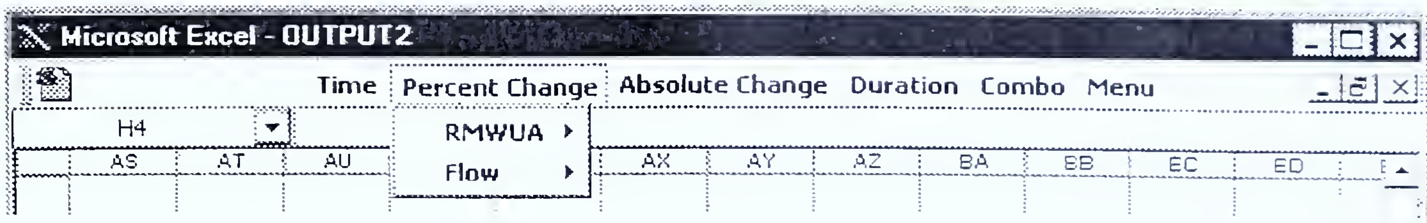


Figure E9. Graphical Output Menu Bar

Graphs of similar items can be overlaid by pressing the combo menu item. This is particularly useful when evaluating impacts of different combinations of withdrawal and passby flow on the same stream. Two different combinations can be plotted on one graph.

To create a combo graph, run the Detailed Analysis Program with both desired combinations of withdrawal and passby flow, and save the output files. After completing each program run, create the individual graphs, leave both charts open, write down the name of the file (e.g., Chart 7 and Chart 9), but do not save them. Then overlay them by pressing "Combo" on the Graphical Output Menu Bar, and then press the "Create Overlay Chart" command that appears immediately below the Combo menu item. The Overlay Graphs dialog box shown in Figure E10 appears. The numbers of the charts to be overlaid (e.g., Chart 7 and Chart 9) can be selected by scrolling each of the list boxes shown. Then press the Create Chart button to create the combined graph.

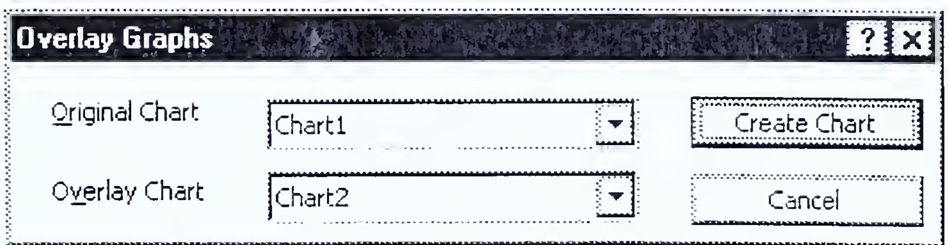


Figure E10. Graph Overlay Dialog Box

E4.1.4 Operation

The output spans many pages, and is most easily analyzed after it is printed. To print the output, press the Print Output button on the Output Data screen shown in Figure E5. The printout of the output table is 13 pages long.

The output table is calculated from an Excel template. The filename for the template is OUTPUTx, where x is a number. If the output from a particular run is not saved in a separate file, it will be overwritten by a subsequent run. To save the output for a particular run for further analysis, change the graphics tool bar on the output screen (Figure E5) to a regular tool bar by pressing the Regular Tool Bar button. Then press the File/Save As command on the toolbar, and enter an appropriate filename in the dialog box that appears. To save graphics, press the Window menu item on the regular toolbar, and select the chart to be saved from the list of open files. Then press the File/Save As command and enter the file name.

After completing a run of either program, close the output file. To close the detailed analysis program output file, press the *lower* close button (lower X shown in upper right corner of Figure E8). Control is transferred to the Streamflow Data Form (Figure E2). If the upper icon is pressed, the entire program will be closed, and control will be transferred to the WINDOWS START screen. Be sure to close the file before exiting the program. There may be problems with subsequent runs if the upper icon is pressed without closing the output file.

The information, as summarized in this program, is different than that contained in the Preliminary Analysis Program, as described in the Data Needs and Calculation Methods section of this appendix.

E4.2 Preliminary Analysis Program

The monthly median time series data is entered in the Preliminary Analysis Program, in the same manner as for the Detailed Analysis Program. This data entry screen differs from the corresponding screen for the detailed analysis program (Figure E2) only in that this data entry screen includes a button called View Last Output that can be used to view the output from a previous run. The data entry part of the data entry screens are identical.

When the streamflow data has been entered, press the Enter New Stream Information button to display the stream data entry dialog box shown in Figure E11. The data is entered in this form in the same manner as for the Detailed Analysis Program. The data entry forms are similar, except that passby flows are not entered for this program. After entering these data, press the Data Entry Complete button to return to the flow data entry screen (Figure E2). Then press the Run New Calculations button on that screen to run the Preliminary Analysis Program. This program will take several minutes to compute the results. Check the status bar at the bottom left corner of the screen to see progress. Run time depends on the computer processor speed and number of streams in the class.

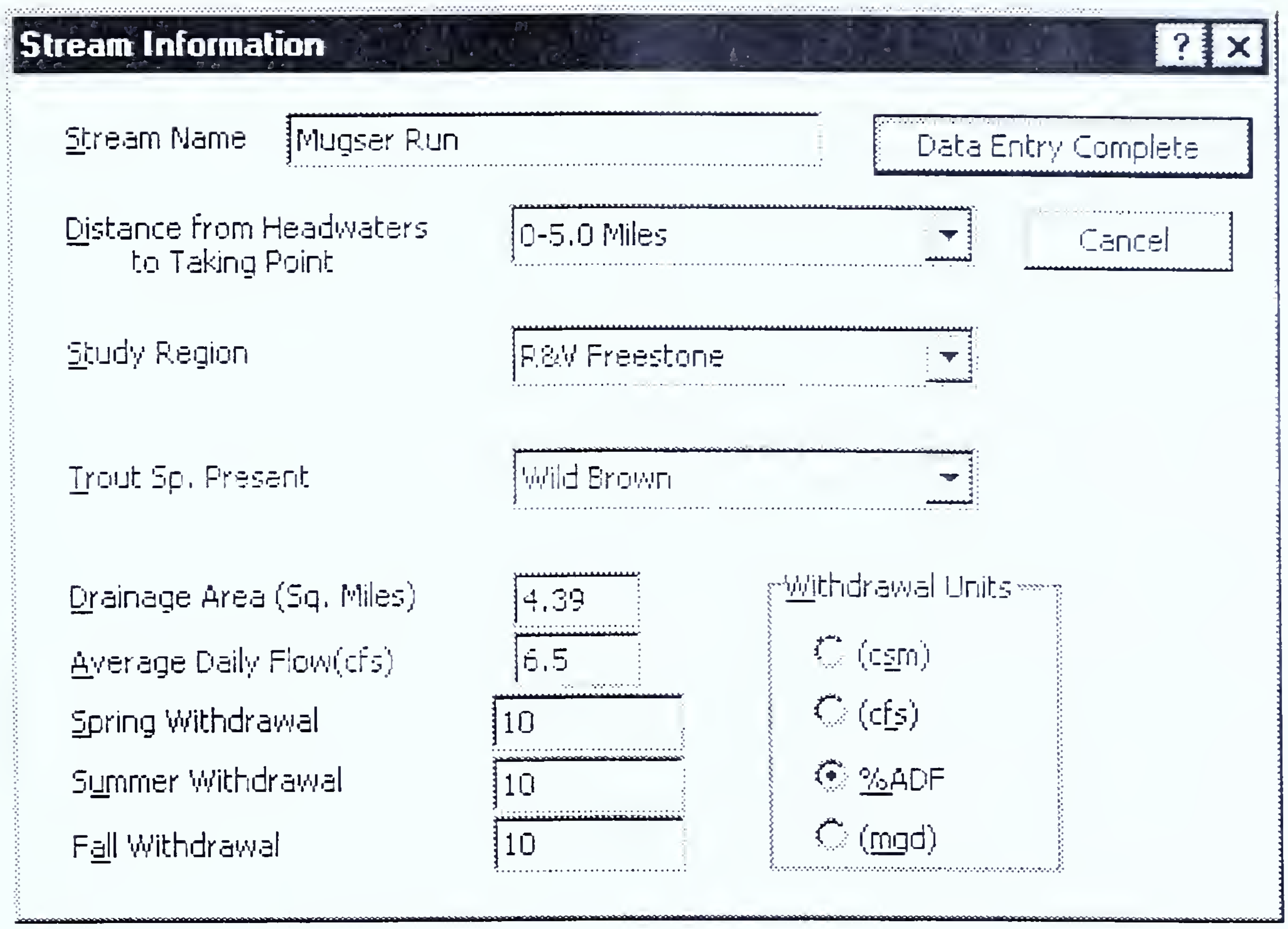
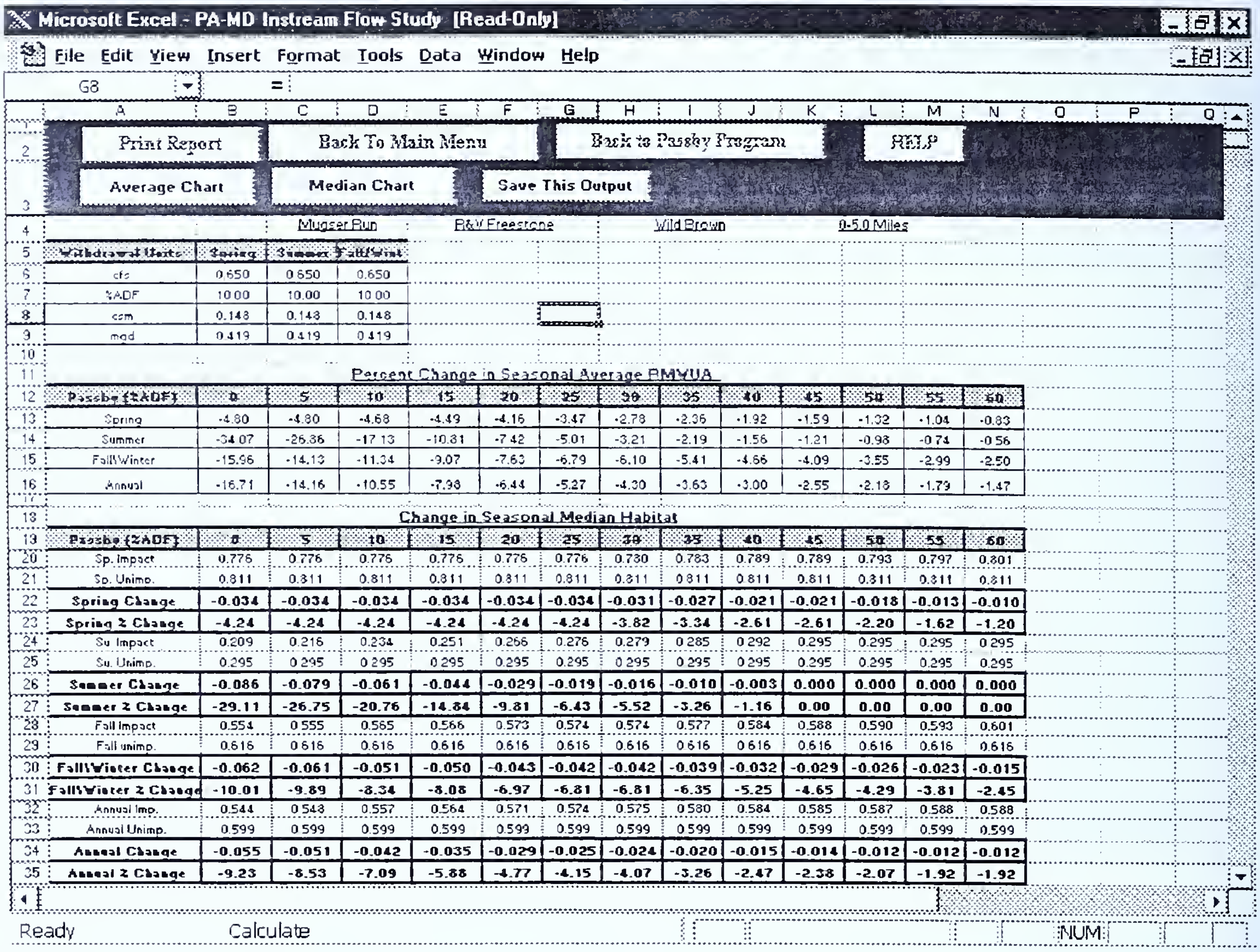


Figure E11. Preliminary Analysis Program Stream Information Dialog Box

When the calculations are completed, an output table similar to that shown in Figure E12 will appear. The table shows the impacts of the specified withdrawal in terms of percent change in seasonal average habitat, as well as absolute and percent change in median seasonal habitat.



Microsoft Excel - PA-MD Instream Flow Study [Read-Only]

File Edit View Insert Format Tools Data Window Help

Print Report | Back To Main Menu | Back to Passby Program | HELP

Average Chart | Median Chart | Save This Output

Mugser Run | B&W Freestone | Wild Brown | 0-5.0 Miles

Withdrawal Units	Spring	Summer	Fall/Wint
cfs	0.650	0.650	0.650
%ADF	10.00	10.00	10.00
csm	0.148	0.148	0.148
mgd	0.419	0.419	0.419

Percent Change in Seasonal Average RMWUA

Passby (%ADF)	0	5	10	15	20	25	30	35	40	45	50	55	60
Spring	-4.80	-4.80	-4.68	-4.49	-4.16	-3.47	-2.78	-2.36	-1.92	-1.59	-1.32	-1.04	-0.83
Summer	-34.07	-26.36	-17.13	-10.81	-7.42	-5.01	-3.21	-2.19	-1.56	-1.21	-0.98	-0.74	-0.56
Fall\Winter	-15.96	-14.13	-11.34	-9.07	-7.63	-6.79	-6.10	-5.41	-4.66	-4.09	-3.55	-2.99	-2.50
Annual	-16.71	-14.16	-10.55	-7.98	-6.44	-5.27	-4.30	-3.63	-3.00	-2.55	-2.18	-1.79	-1.47

Change in Seasonal Median Habitat

Passby (%ADF)	0	5	10	15	20	25	30	35	40	45	50	55	60
Sp. Impact	0.776	0.776	0.776	0.776	0.776	0.776	0.780	0.783	0.789	0.789	0.793	0.797	0.801
Sp. Unimp.	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811	0.811
Spring Change	**-0.034**	**-0.034**	**-0.034**	**-0.034**	**-0.034**	**-0.034**	**-0.031**	**-0.027**	**-0.021**	**-0.021**	**-0.018**	**-0.013**	**-0.010**
Spring % Change	**-4.24**	**-4.24**	**-4.24**	**-4.24**	**-4.24**	**-4.24**	**-3.82**	**-3.34**	**-2.61**	**-2.61**	**-2.20**	**-1.62**	**-1.20**
Su. Impact	0.209	0.216	0.234	0.251	0.266	0.276	0.279	0.285	0.292	0.295	0.295	0.295	0.295
Su. Unimp.	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295	0.295
Summer Change	**-0.086**	**-0.079**	**-0.061**	**-0.044**	**-0.029**	**-0.019**	**-0.016**	**-0.010**	**-0.003**	**0.000**	**0.000**	**0.000**	**0.000**
Summer % Change	**-29.11**	**-26.75**	**-20.76**	**-14.84**	**-9.81**	**-6.43**	**-5.52**	**-3.26**	**-1.16**	**0.00**	**0.00**	**0.00**	**0.00**
Fall Impact	0.554	0.555	0.565	0.566	0.573	0.574	0.574	0.577	0.584	0.588	0.590	0.593	0.601
Fall unimp.	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616	0.616
Fall\Winter Change	**-0.062**	**-0.061**	**-0.051**	**-0.050**	**-0.043**	**-0.042**	**-0.042**	**-0.039**	**-0.032**	**-0.029**	**-0.026**	**-0.023**	**-0.015**
Fall\Winter % Change	**-10.01**	**-9.89**	**-8.34**	**-8.08**	**-6.97**	**-6.81**	**-6.81**	**-6.35**	**-5.25**	**-4.65**	**-4.29**	**-3.81**	**-2.45**
Annual Imp.	0.544	0.548	0.557	0.564	0.571	0.574	0.575	0.580	0.584	0.585	0.587	0.588	0.588
Annual Unimp.	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599	0.599
Annual Change	**-0.055**	**-0.051**	**-0.042**	**-0.035**	**-0.029**	**-0.025**	**-0.024**	**-0.020**	**-0.015**	**-0.014**	**-0.012**	**-0.012**	**-0.012**
Annual % Change	**-9.23**	**-8.53**	**-7.09**	**-5.88**	**-4.77**	**-4.15**	**-4.07**	**-3.26**	**-2.47**	**-2.38**	**-2.07**	**-1.92**	**-1.92**

Ready Calculate NUM

Figure E12. Sample Preliminary Analysis Program Output Table

The output table is a single sheet with three sections that summarize the input and output data. Withdrawal rates for each season are displayed in the first section, in several different units. The percent change in seasonal *average* RMWUA is displayed in the second section for all three seasons, and annually. The seasonal *median* unimpacted and impacted RMWUA, and the percent change in seasonal RMWUA, for each of the preset passby flows (percent ADF) are displayed in the third section for each season, and annually. The unimpacted and impacted RMWUA values are shown, along with the percentage change.

To print the output table, press the Print Report button on the Passby Program output screen (Figure E12). To save this output table to a file, press the Save This Output button to display a pop-up menu, which allows entry of a name for the file. If the file is not saved, it will be overwritten by the next program run.

The output can be displayed graphically by pressing either the Average Chart or the Median Chart buttons on the output screen. The Average Chart button produces a graph of the seasonal average RMWUA versus passby flow, with one curve for each season. The Median Chart button produces a

similar graph of seasonal median RMWUA versus passby flow. Both graphs will be printed automatically.

To close the preliminary analysis program output, press either the Back to Main Menu button or the Back to Passby Program button on the output screen (Figure E12). If the first button is pressed, control is transferred to the Main Menu (Figure E1). If the second button is pressed, control will be transferred to the passby program streamflow data input screen, which is identical to the Streamflow Data Form, shown in Figure E2.

The information contained in the report can be used to determine feasible passby flows for each season. The impacts of feasible combinations of withdrawal and passby flow should be evaluated using the detailed analysis program.

Key to Study Sites Shown on Plate 1

Stream Name	Number
Bear Run	1
Big Fill Run, Seg. 1	2
Big Fill Run, Seg. 2	3
Big Run	4
Fowler Hollow, Seg. 1	6
Fowler Hollow, Seg.2	7
Green Creek, Seg. 1	9
Green Creek, Seg. 2	10
Green Creek, Seg. 3	11
Horning Run	12
Kansas Valley Run	13
Laurel Run (Juniata)	15
Mile Run	16
Mugser Run, Seg. 1	17
Mugser Run, Seg.2	18
Rapid Run, Seg. 1	19
Rapid Run, Seg. 2	20
Rapid Run, Seg. 3	21
Salem Creek	22
Sand Spring Run	23
Swift Run	24
Vanscoyoc Run	26
Wapwallopen Creek, Seg. 1	27
Wapwallopen Creek, Seg. 2	28
Wapwallopen Creek, Seg. 3	29
Wapwallopen Creek, Seg. 4	30
Antes Creek	31
Big Spring Creek	32
Boiling Spring Run	33
Bushkill Creek, Seg. 1	34
Bushkill Creek, Seg. 2	35
Cedar Creek (Lehigh)	36
Cedar Run (Centre)	37
Cedar Run (Cumberland)	38
Falling Spring Run	39
Honey Creek	40
Letort Creek, Seg. 1	41
Letort Creek, Seg. 2	42
Lick Creek	43
Little Fishing Creek	44
Long Hollow Run	45
Monocacy Creek, Seg. 1	46
Monocacy Creek, Seg. 2	47
Monocacy Creek, Seg. 3	48
Nancy Run	49
Penns Creek, Seg. 1	50
Penns Creek, Seg. 2	51
Penns Creek, Seg. 3	52
Potter Creek	53

Stream Name	Number
Spring Creek (Berks)	54
Spring Creek, Seg. 1	55
Spring Creek, Seg. 2	56
Spring Creek, Seg. 3	57
Spring Creek, Seg. 4	58
Trindle Spring Run	59
Trout Creek	60
Beech Run	61
Benner Run	62
Bloomster Hollow	63
Cherry Run	64
Coke Oven Hollow	65
Cush Creek, Seg. 1	66
Cush Creek, Seg. 2	67
Dunlap Run	68
E. Br. Spring Creek, Seg.2	70
Fall Creek, Seg. 1	71
Fall Creek, Seg. 2	72
Findley Run	73
Lower Two Mile Run, Seg. 1	74
Lower Two Mile Run, Seg. 2	75
Lyman Run	76
McClintock Run	77
McEwen Run	78
Meyers Run	79
Mill Run	80
Red Run	82
Seaton Run	83
Strange Hollow	84
Tannery Hollow	85
Warner Brook	86
Whites Creek, Seg. 1	88
Whites Creek, Seg. 2	89
E. Br. Raven Creek	90
Granville Run	91
Laurel Run (Huntingdon)	92
Baisman Run	93
Basin Run, Seg. 1	94
Basin Run, Seg. 2	95
Cooks Branch	96
First Mine Branch	97
Gillis Falls, Seg. 1	98
Gillis Falls, Seg. 2	99
Greene Branch	100
Norris Run	101
Piney Run	102
Third Mine Branch	103
Timber Run	104

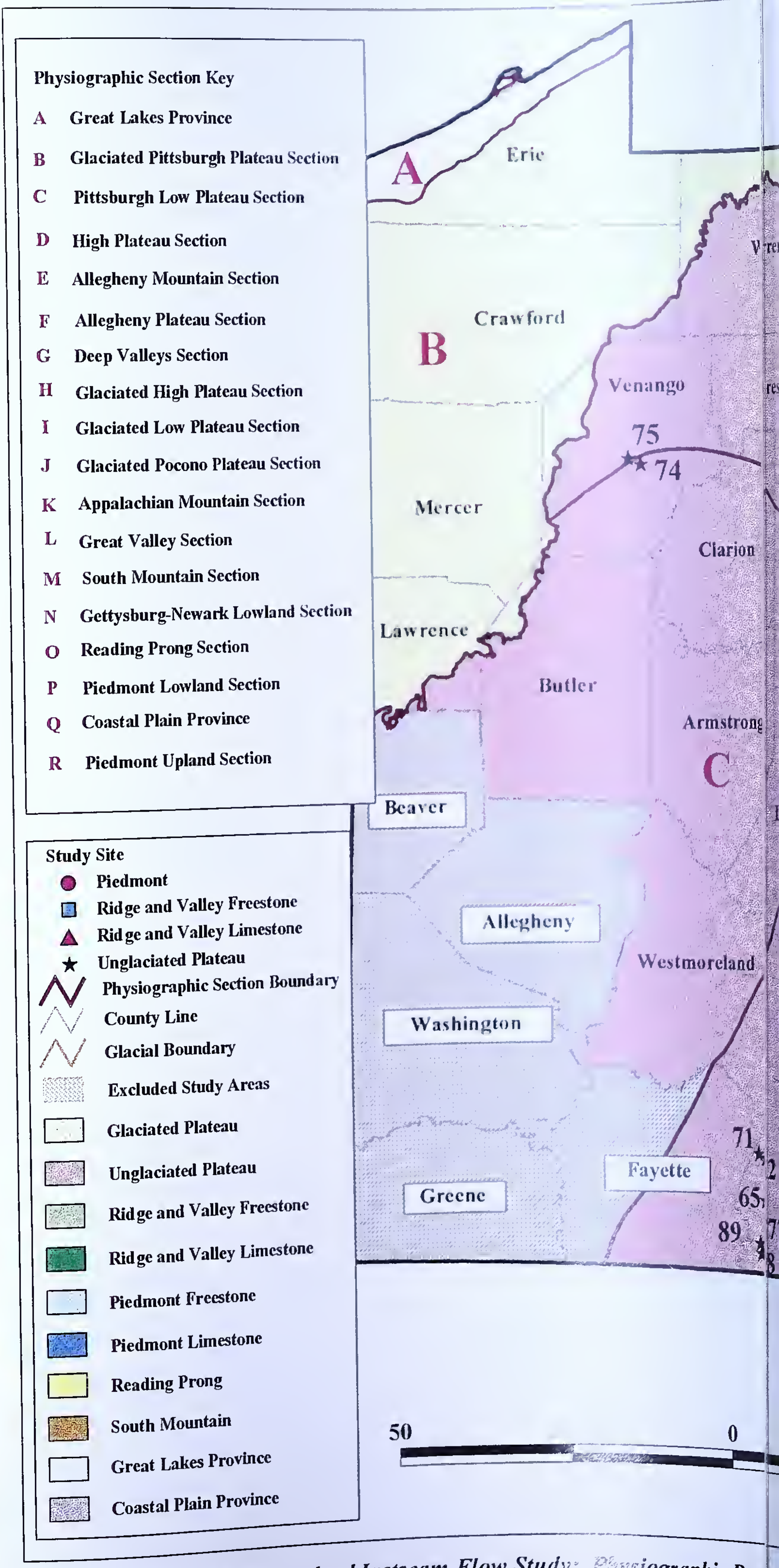
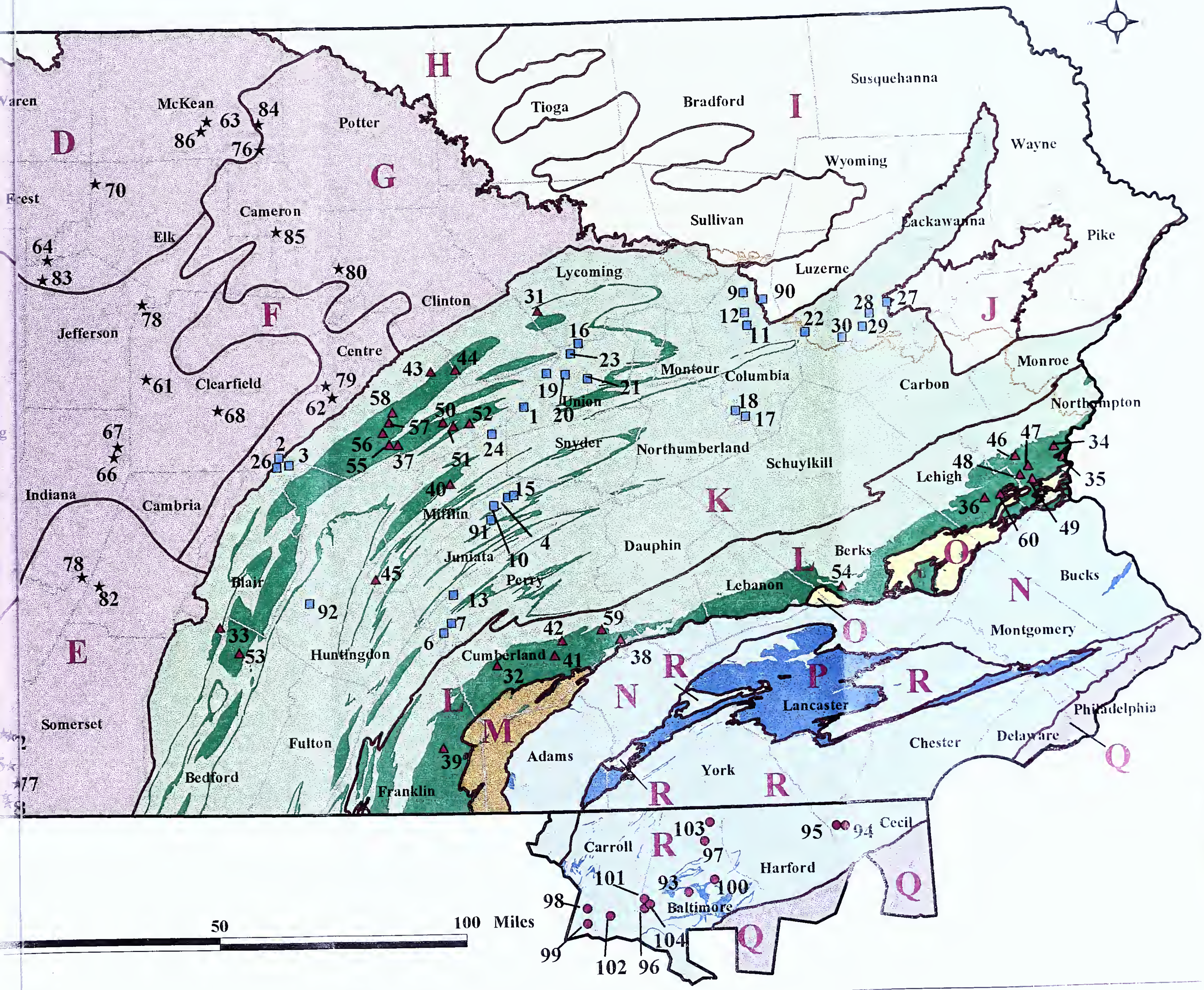


Plate 1. Pennsylvania-Maryland Instream Flow Study: Physiographic Regi



gios, Study Regions, Limestone Areas, and Study Site Locations

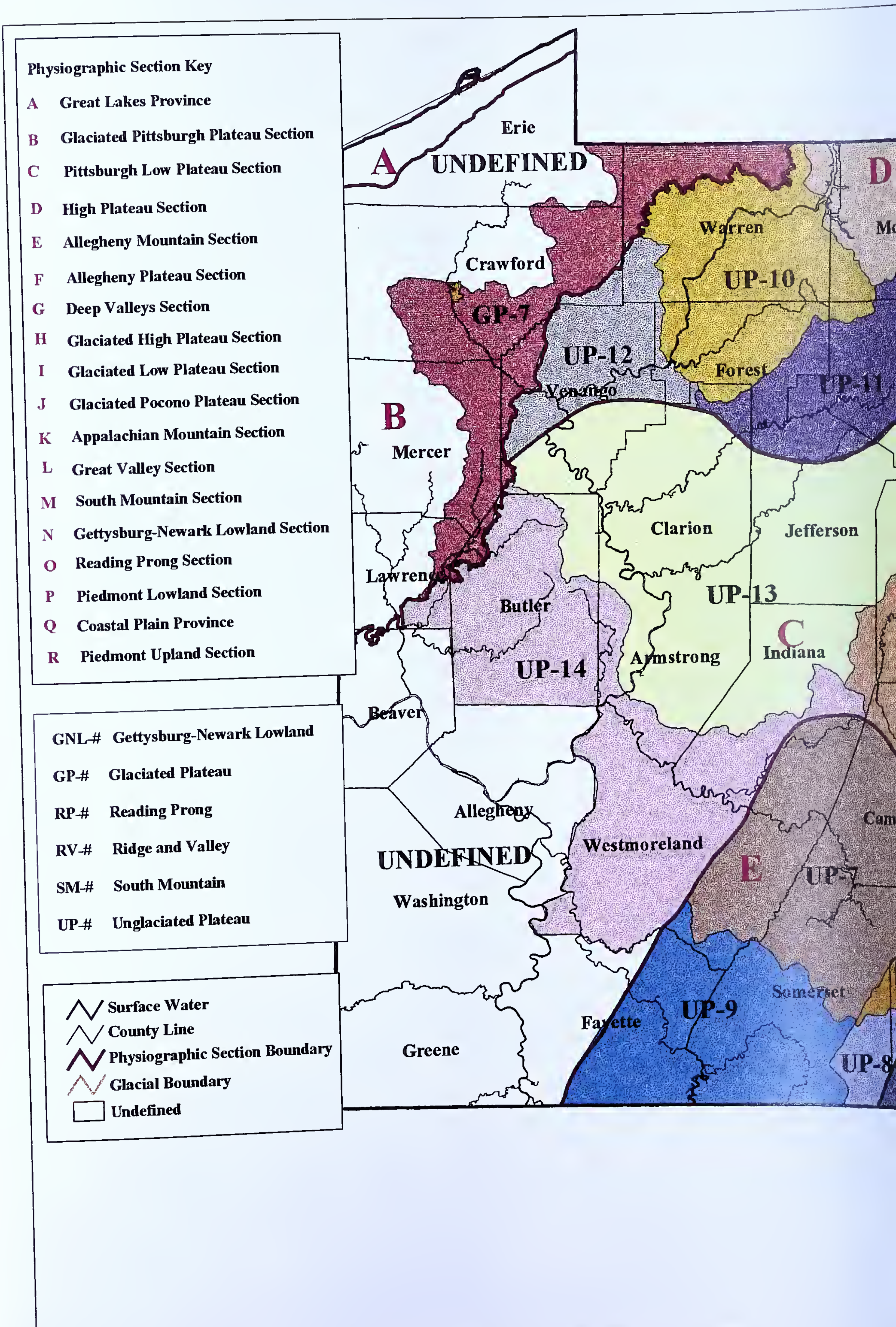
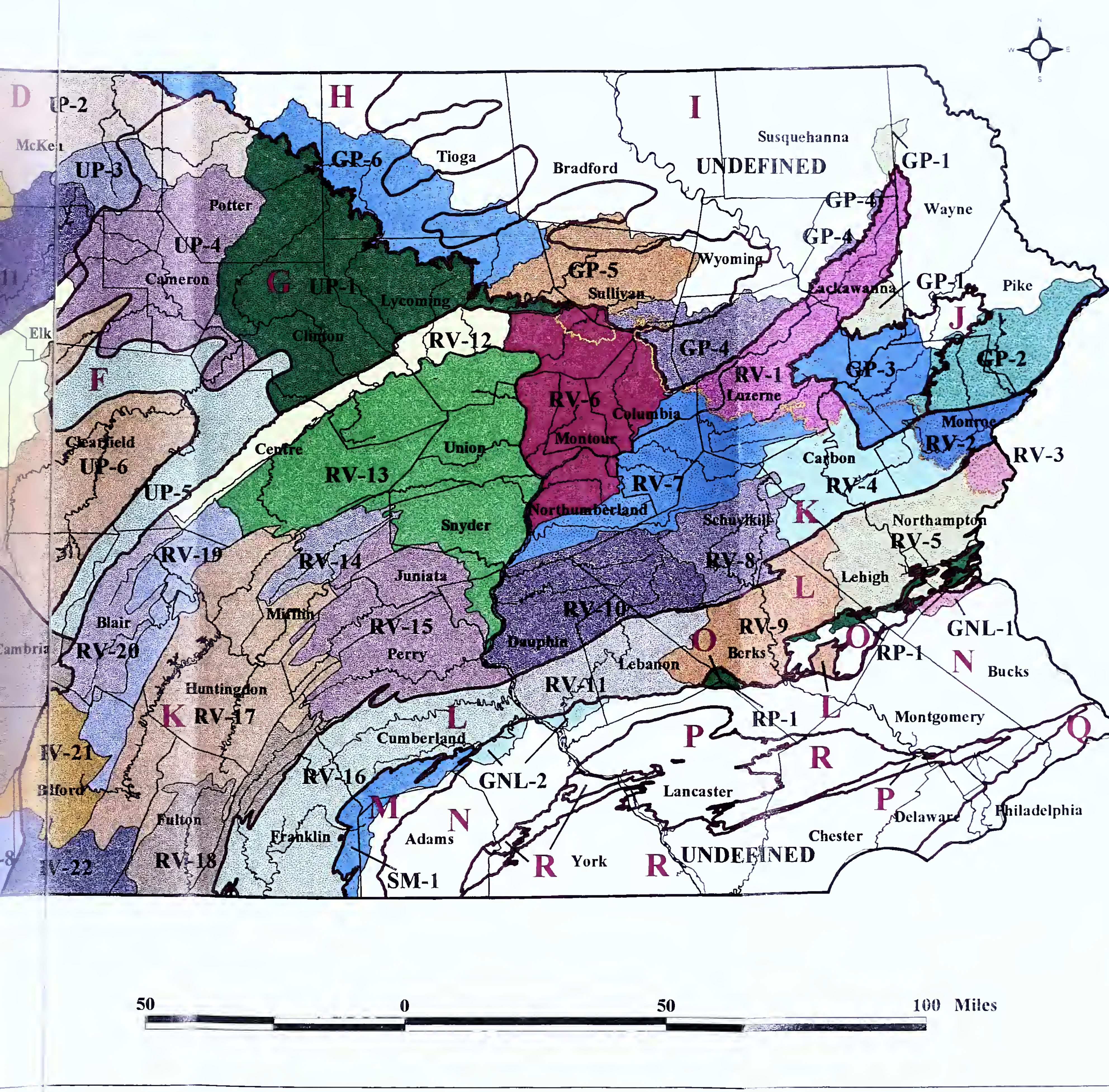


Plate 2. Pennsylvania-Maryland Instream Flow Study: Hydrologic Regions



D
UP-2
McKean
UP-3
Potter
UP-4
Cameron
Elk
F
Clearfield
UP-6
UP-5
H
GP-6
Tioga
G
UP-1
Lycoming
Clinton
Centre
RV-12
RV-13
Union
Snyder
Bradford
I
UNDEFINED
Susquehanna
GP-1
Wayne
GP-4
Wyoming
GP-5
Sullivan
Lackawanna
GP-1
Pike
J
GP-2
GP-4
GP-3
RV-1
Luzerne
RV-6
Columbia
Montour
Monroe
RV-2
RV-3
Carbon
RV-4
RV-7
Northumberland
Schuylkill
K
Northampton
RV-5
RV-8
Lehigh
L
RV-19
RV-14
Juniata
Mifflin
Blair
RV-15
RV-10
Dauphin
RV-9
Berks
O
O
RP-1
GNL-1
N
Bucks
Cambria
RV-20
Perry
Lebanon
RV-11
Huntingdon
K
RV-17
L
Cumberland
RP-1
L
Montgomery
Q
RV-21
Bedford
RV-16
GNL-2
P
R
Lancaster
P
Delaware
Philadelphia
Fulton
M
N
Franklin
Adams
Chester
RV-22
RV-18
SM-1
R
York
R
UNDEFINED
50
0
50
100 Miles